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Cereal processing,
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The Chemistry and Technology of
Cereals as Food and Feed

Prepared by a group of specialists and edited by

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Preface

A comprehensive survey of the chemistry and technology of the cereal industries has never been published although many good treatments of such specialized subjects as milling and baking are available. This lack has handicapped students and workers in cereals and allied fields, as attested by the opinions expressed to the editor and the publisher when they made known their intention of compiling such a survey. It is the sincere hope of the editor that the present volume will remedy the deficiencies of the past.

Some limitations on subject matter were necessary in order to keep the length of the book within reasonable bounds. Only cereal grains have been dealt with: soybeans, buckwheat, etc., are not discussed. Forage uses of cereal plants have been considered only when they have an important bearing on other uses of the grains. Non-feed and non-food processing methods have usually been ignored, although in some cases (such as the wet-milling chapter), brief discussions of these matters have been necessary in order to define completely the more pertinent processing methods. For the most part, emphasis has been placed upon procedures in the United States.

Breadth, rather than depth, of coverage was sought. Where possible, bibliographies of considerable length have been included to direct the reader to more extensive discussions of the finer points of the art.

Authors were selected from among those scientists and technologists who have a close and continuing acquaintance with commercial practices in their specialized area. Pre-eminence in professional reputation was considered a necessary qualification, but voluminous prior publication was not. Attempts were made to obtain authors who had fresh and non-derivative views of their field.

For the convenience of the reader, the book is divided into three sections. The first series of chapters deals with the quality characteristics and the production of cereal grains. These chapters provide a background for the discussions dealing with processing methods which are found in Section II. The final section includes chapters concerned with some of the more important characteristics of broad classes of grains and grain products.

This book is not directed to cereal chemists alone, although its most obvious appeal is to that group. Other food technologists should benefit

from the unified treatment of the subject. Agronomists should find it particularly useful because of the technique of relating raw material quality to processing variables and finished product characteristics. Marketing and sales personnel should find the material presented to be of value in orienting themselves on factors affecting product quality and supply.

A listing of all the persons who have supplied counsel, information, reviews, illustrative material, and encouragement would require a chapter by itself. Acknowledgements must of necessity be incomplete for this reason, but the following list includes persons other than authors who have reviewed chapters or made other substantial and time consuming contributions to the book.

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In spite of thorough reviews by the above persons and others, it is inevitable that, in a book of this size, errors will creep in. The editor will deem it a valuable favor if the reader will inform him of errors which are detected and will make suggestions of changes which can be incorporated into subsequent editions.

Contributors who are employees of any branch of the Federal government are, of course, expressing in these articles only their own opinions and not those of their employer.

SAMUEL A. MATZ

February 1, 1959

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SECTION I

The Cereal Grains

John A. Shellenberger

Wheat

HISTORICAL ASPECTS OF WHEAT PRODUCTION

Origin of the Wheat Plant

Notwithstanding many years of intensive effort and extensive investigation, it has not been determined accurately either when or where the first cultivated wheat originated. At the beginning of recorded history, wheat was already an established crop whose origin was unknown (Anon. 1953).

The ancestry of the common races of wheat grown today remains problematical; however, a good deal of evidence indicates that cultivated einkorn was developed from a type of wild grass native to the arid pasture lands of Southeastern Europe and Asia Minor.

Emmer, which is generally regarded as one of the ancestors of the wheats grown today, closely resembles a wild species of wheat found in the mountainous regions of Syria and Palestine. It is a much better wheat than einkorn, which gives low yields and dark, somewhat bitter kernels. Since crude wheat-type plants, such as einkorn and emmer, and many wild species of grass were growing centuries ago, Percival (1921) concluded that bread wheat originated by hybridization from an emmer type and a wild species of grass.

Advances in nuclear physics have helped immensely to fix the dates in history for the beginning of agricultural plants. While plants are alive, they absorb from the atmosphere carbon dioxide which contains traces of radioactive carbon 14. When plants die, the supply of radioactive carbon ceases, because carbon dioxide is no longer being ingested. Since carbon 14 slowly disintegrates, and since the rate of loss of radioactivity is known, the time of death can be established by determining the ratio between the radioactivity of the carbon in living and in dead plants.

Evidence of this kind places the beginning of the cultivation of wheat roughly six thousand years, ago. Cultivation began in the Syria-Palestine area and spread west and south into Egypt and east into Iran. From Iran, wheat spread into India, China, Russia, and Turkistan; from Egypt, Palestine, and Syria, it moved into South and Central Europe. The first wheat to reach Europe was in the form of einkorn and emmer about 3000 B.C. Bread wheats, such as we know today, began to spread over Europe from

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Courtesy Dept. Agronomy, Kansas State College

FIG. 1. THE LESS COMMON SPECIES OF WHEAT COMPARED WITH *Triticum Vulgare*, THE SPECIES COMMONLY GROWN

Left to right, spikes of *T. vulgare*, club, einkorn, emmer, durum, spelt, poulard and Polish

southern Russia about 2000 B.C. The less common species of wheat compared with the types grown today are shown in Fig. 1.

Cultivation of Wheat

For centuries, agriculture was so primitive that any attempts to describe its beginnings become a matter of surmise and conjecture. The history of the start of cultivation of cereal crops far precedes any documents; therefore, it can only be supposed that the use of certain grains for food led primitive man to develop the fundamental art of scattering seeds on rough clearances of the soil. Gradually, crude methods for cleaning land and cultivating the soil developed. The earliest discoveries of archeologists show that even neolithic man had wheat grains not much different from the types known today. With the advent of written history at the time of the Greeks and Romans, agriculture was a highly developed art (Storck and Teague 1952).

Once the avenues of commerce were formed, wheat culture spread rather rapidly throughout the world. Wheat was unknown in both North and South America until brought to the Continent by early explorers from Europe. Because the wheat plant is extremely adaptable to environmental conditions, wheat production encircles the globe. Harvesting is being done somewhere on the earth every month of the year, as shown in Table 1. Wheat is grown from the latitude close to the Arctic Circle in the Northern Hemisphere, both in Canada and in the Scandinavian countries, and beyond the 40th parallel in South America and New Zealand.

TABLE 1

THE WORLD'S WHEAT HARVEST

Month	Country	Month	Country
January	Australia New Zealand	July (*Contd.*)	England U.S.S.R. (South) Switzerland United States
February	Egypt (Upper)		
March	India	August	Belgium Canada Denmark England U.S.S.R. (Central) Poland Netherlands United States (North)
April	Middle East Egypt (Lower) Mexico		
May	China Japan Morocco United States (Texas)	September and October	Norway U.S.S.R. (North) Sweden
June	France Greece Italy Spain Turkey United States	November	Africa (South) Peru
		December	Australia Argentina Africa Chile New Zealand
July	Austria Hungary Bulgaria		

The cultivation of wheat varies from primitive methods, still practiced in a few areas of the world, to complete mechanization of the entire operation from soil preparation to harvesting. In the more important wheat-producing areas land is plowed, prepared for seeding, and sowed by tractor equipment operation, after which the crop is harvested by self-propelled combines and the wheat transported to storage or to railway terminals by truck.

BOTANY OF THE WHEAT PLANT

Germination and Growth

Development of the wheat plant starts with the germination of the seed. Before sown seed can germinate and growth proceed, several conditions must be fulfilled, such as: (1) an adequate amount of moisture in the soil, (2) sufficient soil warmth, and (3) a supply of oxygen. Lack of water, heat, or air will prevent germination.

The wheat kernel, after planting, absorbs moisture and becomes swollen. Soon the pericarp at the germ end of the kernel ruptures and the plumule of the embryo emerges. Later the primary root emerges, followed a few hours later by the first pair of lateral rootlets. The roots

grow and expand to provide the plant with water and soil nutrients. The acrospire develops and pushes up through the soil to emerge as a shoot, forming the first foliage. The leaves of grasses (wheat is classified as a grass) are attached to the joints of the stem alternately, in a manner which produces two opposite longitudinal series of leaves. At the base of the leaf-blade of wheat, a membrane structure nearly surrounds the stem. Leaves grow in length from the base area near the stem; therefore, grazing or cutting back the leaves does not prevent renewed growth.

Courtesy of G. E. Scott and E. G. Heyne, and K. F. Finney, Agronomy Journal

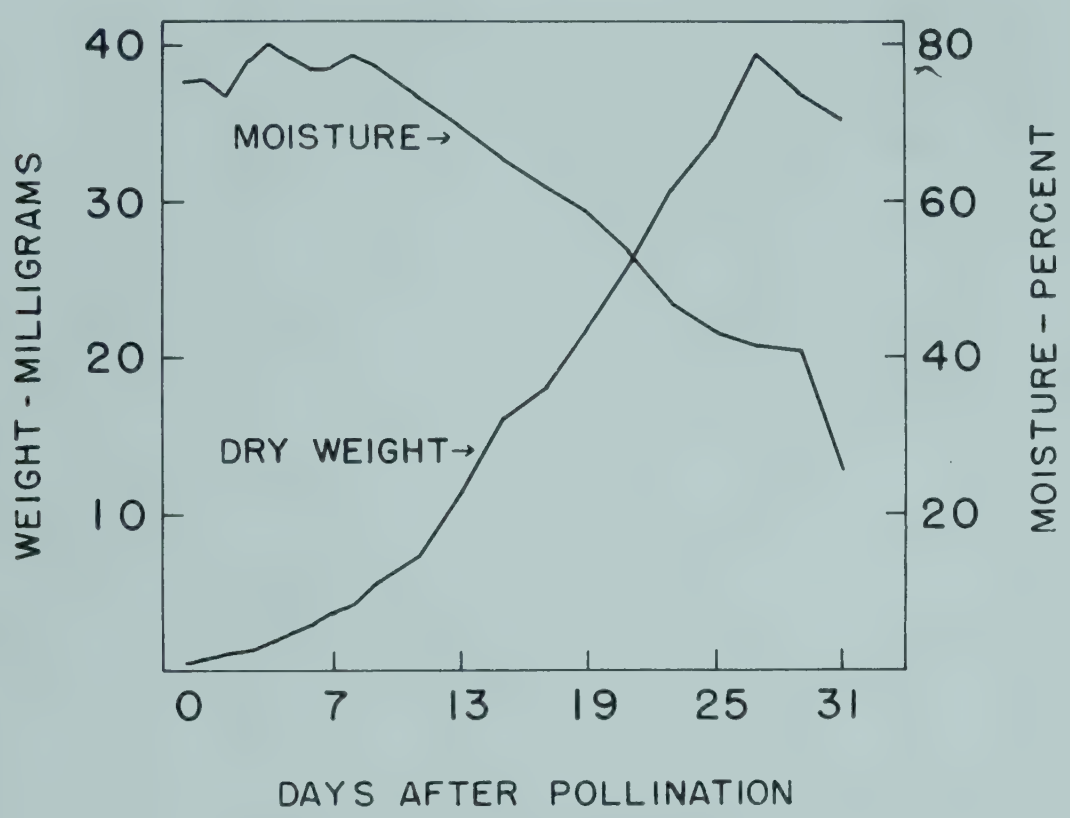
FIG. 2. RATE OF DEVELOPMENT OF HARD RED WINTER KERNEL
Numerals indicate number of days after pollination

As the wheat plant develops, the stem extends, and lateral buds formed near the surface of the soil grow into short stems, thus producing a branching close to the ground which is called "tillering." These "tillers" later form the straws of the plant and can vary in number up to 100 from a single kernel. The inflorescence or ear of wheat consists of the rachis which has on alternate sides a number of spikelets. At the base of the spikelets are two chaffy scales called glumes, followed by a number of flowers arranged along the rachilla, and terminated by the beard or awn.

When the ear or head emerges from the upper leaf sheath, flowering takes place. The first spikelets to flower are usually toward the middle of

the ear, and the whole ear completes flowering under normal weather conditions in five or six days. After fertilization, the grain begins to develop in volume, increasing as illustrate in Fig. 2.

Recent work on the daily development of the wheat kernel was reported by Scott (1955) and Scott *et al.* (1957). The dry weight and moisture content of wheat kernels harvested at various dates after pollination were studied, as shown in Fig. 3. The dry weight of individual kernels increased slowly for the first few days after pollination but there-



Courtesy of G. E. Scott, E. G. Heyne, and K. F. Finney, Agronomy Journal

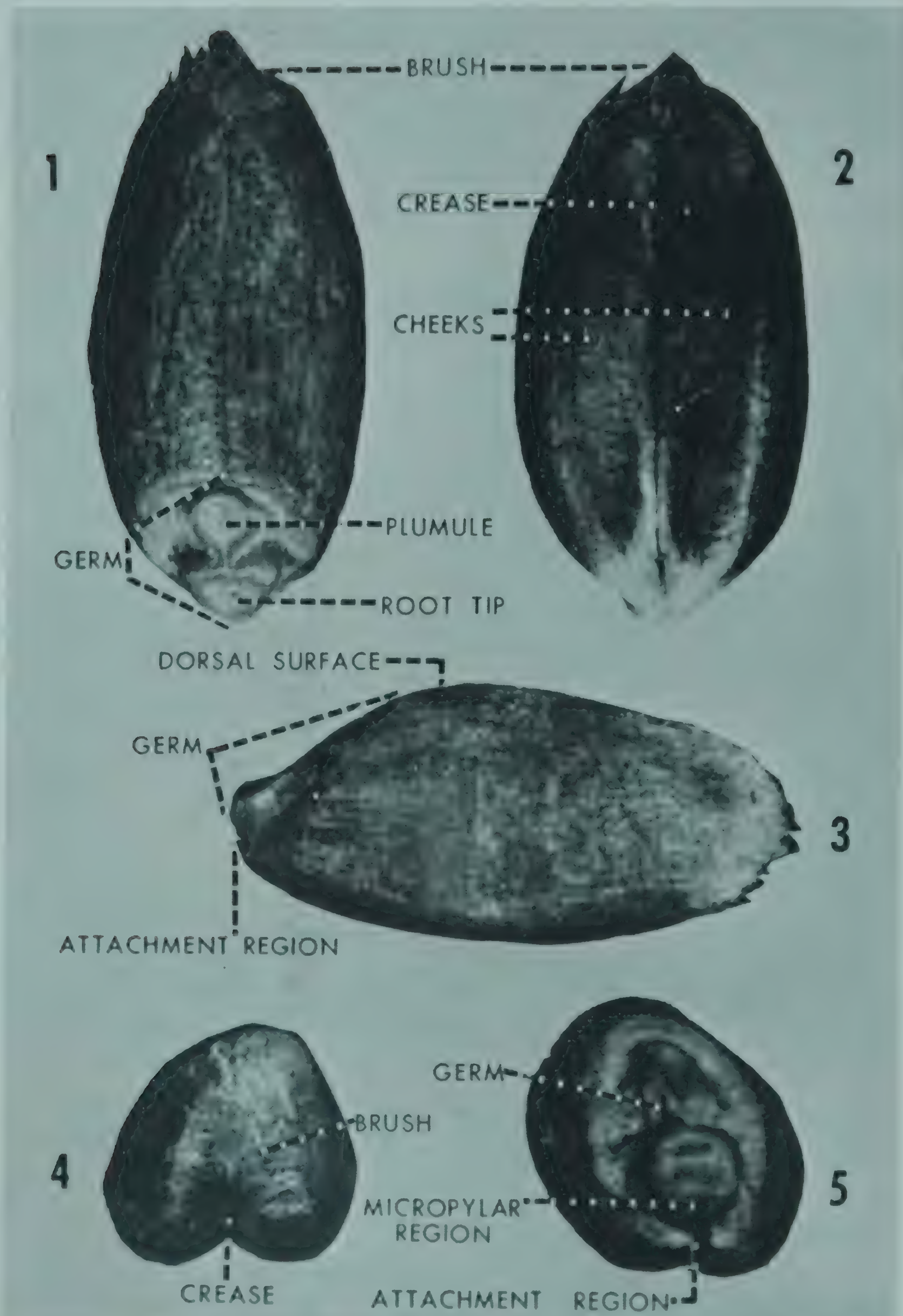
FIG. 3. DRY WEIGHT AND MOISTURE CONTENT OF HARD RED WINTER WHEAT KERNELS HARVESTED AT VARIOUS DATES AFTER POLLINATION

after increased rapidly until the kernel appeared physiologically mature on the 27th day. Kernel moisture content reached a maximum on the 15th day, then decreased gradually until the 29th day, when rapid loss of water began.

Structure of the Wheat Kernel

Percival (1921) has described the wheat kernel in great detail. The kernel or seed of the wheat plant is a nut-like fruit called by botanists, a caryopsis. It contains a single seed or kernel enclosed within a thin shell, and the seed cannot, as is true with some fruits, be separated readily from the shell, or pericarp.

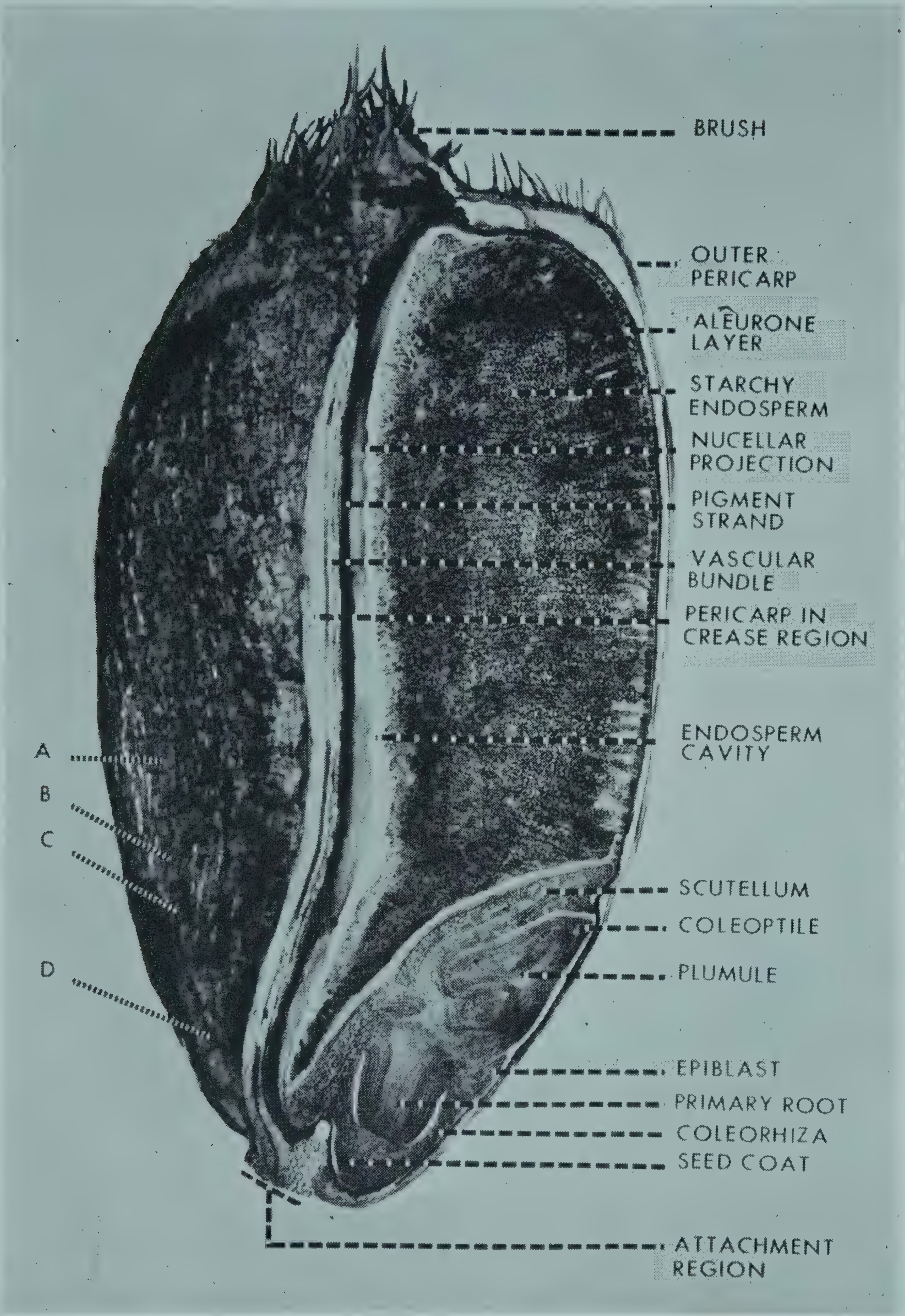
The main features of the wheat kernel can best be described in terms of the rounded or dorsal side and the ventral or crease side. A deep



Courtesy of Northern Utilization Research and Development Division U.S. Dept. Agr.

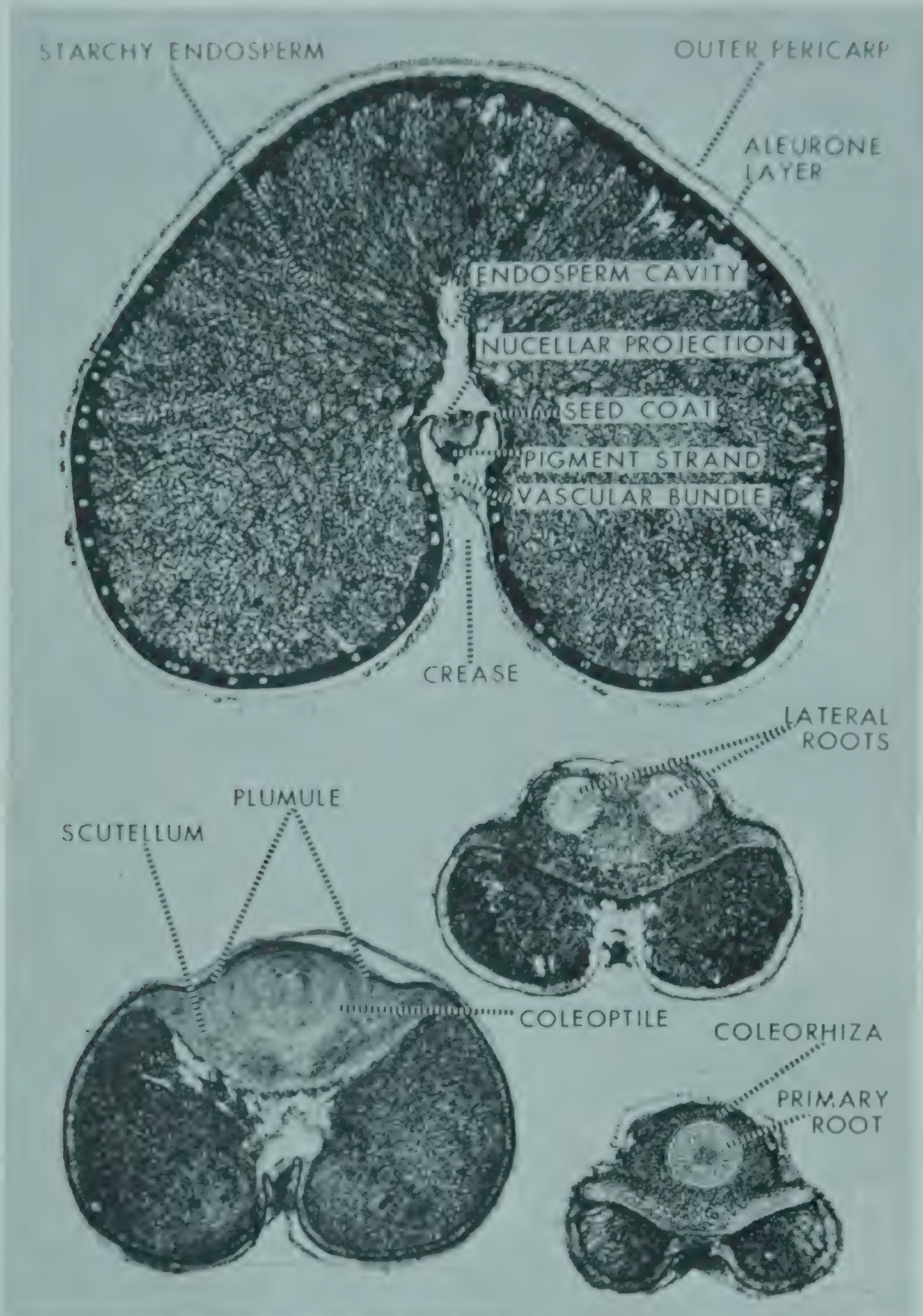
FIG. 4. EXTERNAL VIEWS OF A TYPICAL HARD RED WINTER WHEAT KERNEL

1-back (dorsal) face; 2-crease (ventral) face; 3-side; 4-brush; 5-germ end



Courtesy of Northern Utilization Research and Development Division U.S. Dept. Agr.

FIG. 5. VIEW OF WHEAT KERNEL BISECTED LONGITUDINALLY



Courtesy of Northern Utilization Research and Development Division U. S. Dept. Agr.

FIG. 6. TRANSECTION OF WHEAT KERNEL

groove or crease extends the entire length of the wheat kernel. At the apex or small end of the grain there are many short fine hairs known as brush hairs. The outer bran or seed coat consists of three layers known as the epidermis, epicarp, and endocarp. The other portions of the kernel are the germ and endosperm. Wheat kernels vary considerably in size, form, and color.

From a processing standpoint, the object of milling is to separate the three main parts of the wheat kernel into products commonly known as flour, bran, and germ. The wheat type, chemical composition, and physical structure, combined with the equipment used and skills applied, determine the success of the milling operation.

Detailed studies of the structure of the mature wheat kernel have been reported by Bradbury *et al.* (1956, 1956A, 1956B, and 1956C). External, transected, and longitudinally bisected views of the wheat kernel as described by these authors are shown in Figs. 4, 5 and 6. They report the bran to be composed of the pericarp and the outermost tissues of the seed, including the aluerone layer, and also that there is no line of cleavage between the bran and starchy endosperm. This accounts for some of the difficulties encountered in flour milling when a complete separation between the two is desired. The germ, however, is a separate entity, and no breakage of cell walls is required to separate germ from endosperm.

The various parts of the wheat kernel are named and shown in the illustrations. The tissues of the pericarp form a thin protective covering over the entire wheat kernel. Microscopic examination of the pericarp shows that it is composed of several layers, named from the outside of the kernel inward as follows: epidermis, hypodermis, remnants of thin-walled cells, intermediate cells, cross cells, and tube cells. The hairs of the brush are extensions of epidermal cells. Any damage to the protective covering of the kernel, particularly moisture loss or gain, is important in considerations of storage. Bradbury *et al.* (1956) have presented data to show that from 25 to 73 per cent of the kernels of commercial lots of wheat had endosperm or germ exposed as a result of mechanical injury to the pericarp or seed coat. This explains why difficulties occur in cleaning, tempering, and milling wheat.

CLASSIFICATION OF WHEAT

Species

Wheat belongs to the grass family, **Gramineae (Poaceae)**, and the genus *Triticum*. There are several bases that may be used to classify wheat, but the commonest and most important grouping is based on botanical characteristics. Percival (1921) described 18 species, but only a few are agriculturally important.

The important species of *Triticum* follow:

T. aegilopoides and *T. monococcum* possess perhaps seven pairs of chromosomes and are somewhat more grass-like in appearance than are the common wheat varieties. The kernels are small, flinty, and rice-like.

T. compactum, or club wheat, has 21 chromosomes. This species is characterized by club-shaped spikes. The kernels are plump, soft, and mealy and may be either white or red.

T. dicoccoides has 14 chromosomes and is a form of wild emmer. This species has certain disease-resistant qualities and has been used successfully in crosses with hard red spring wheat varieties. The kernels are long, narrow and flinty.

T. durum has 14 chromosomes. It is often referred to as macaroni wheat, because hardness of the endosperm makes it well suited for manufacturing of macaroni and related products.

T. polonicum, known as Polish wheat, has 14 chromosomes. The grains are flinty, long and narrow. This species is not of great commercial importance.

T. spelta or speltz has 21 chromosomes and retains its glumes like emmer with which it is often confused. The kernels are long and flinty. This species has no economic importance in the United States.

T. timopheevi has 14 chromosomes. It is a fairly recent species possessing considerable disease-resistant qualities.

T. turgidum or cone wheat has 14 chromosomes. The kernels are large, plump, and usually mealy.

T. vulgare is a 21 chromosome wheat commonly referred to as a bread wheat. This species varies in size of kernel, can be either flinty or mealy, and can have either spring or winter habit. Most of the wheat varieties used for bread-baking are of this species.

Methods for Distinguishing Wheat Varieties

It is difficult or impossible to identify, within a class, most varieties of wheat by an examination of the seed. Field appearance and all plant characteristics usually need to be studied before identification is possible. When need arises, it has proved feasible to present in a simplified, nontechnical manner, based on morphological characteristics, methods for the identification of some varieties of wheat. An example of this is the identification of hard red winter wheat varieties as a help to wheat growers, grain dealers, and millers. Several publications on the subject of kernel identification have appeared, one of the most recent being Extension Circular No. 254, of the Kansas Agricultural Experiment Station (Anon. 1956).

Identification is based on kernel characteristics such as: color, texture, shape, germ, back, crease, cheeks, and brush, plus other considerations of wrinkling, depressions, fine lines, or sharply outlined germ. Certain varieties less desirable from the standpoint of baking quality include Red Chief and Chiefkan which can be distinguished from turkey-type

FIG. 7. DISTINGUISHING WHEAT HEAD AND KERNEL CHARACTERISTICS OF PONCA (LEFT) AND RED CHIEF (RIGHT)
These are examples of good and poor quality varieties

wheats easily by field appearance, since the former varieties are beardless. Kernel characteristics are also sufficiently different to be recognizable by persons who have had some instruction in wheat kernel identification. Fig. 7 illustrates the distinguishing characteristics of Red Chief kernels compared with Ponca, one of the wheat varieties grown extensively in the Southwest.

PRODUCTION STATISTICS

World Wheat Production

It is difficult to obtain a completely reliable picture of the quantity of wheat grown in various parts of the world because of continually changing conditions. Somewhere in the world, wheat is being planted or harvested throughout the year; consequently, there is no ideal time to choose as a basis for estimating total production. Another complication is the absence of data on wheat production from U. S. S. R. and China.

Wheat is grown to some extent on all six continents, but as shown in Table 2, about nine-tenths of the total is grown in Europe, Asia, and

TABLE 2

WHEAT PRODUCTION BY CONTINENTS

Continent	Average 1935–39	Average 1945–49	1955
	1,000 Bushels	1,000 Bushels	1,000 Bushels
Europe	2,840,000[1]	2,148,000[1]	1,790,000[2]
Asia	1,558,000	1,587,000	1,815,000
North America	1,086,000	1,581,000	1,463,000
South America	280,000	265,000	300,000
Africa	143,000	134,000	190,000
Oceania	176,873	182,983	202,800

[1] U.S.S.R. production in both Asia and Europe.
[2] Does not include China or U.S.S.R.

TABLE 3

PRINCIPAL WHEAT-PRODUCING COUNTRIES OF THE WORLD (CHINA AND U.S.S.R. EXCLUDED) 1955–57 AVERAGE[1]

Country	1,000 Bushels	Country	1,000 Bushels
North America:		Asia:	
Canada	488,570	Iran	90,183
United States	953,088	Turkey	255,980
		India	325,353
Europe:		Pakistan	128,297
France	339,366	Japan	51,120
West Germany	130,587		
Greece	51,173	Africa:	
Italy	326,230	Egypt	54,700
Spain	155,000		
Yugoslavia	87,390	South America:	
		Argentina	226,293
		Oceania:	
		Australia	110,200

[1] From U. S. Dept. Agr.

North America (Nauheim *et al.* 1958). Contrary to popular belief, even though Asia is considered a rice-producing and consuming area, wheat production is high, averaging in recent years about 1.8 billion bushels. World production of wheat, excluding China and U.S.S.R., has increased from about 3.6 billion bushels to 7 billion bushels in the past half century. Present wheat production in Asia exceeds that in either North America or Europe, excluding the Soviet Union. The three largest wheat producing countries are the United States, the Soviet Union, and China. The principal wheat producing countries are listed in Table 3. World wheat production areas are shown in Fig 8.

Production in the United States

Wheat is grown widely throughout the United States as is shown in Fig. 9. The principal wheat types by areas are hard spring wheat in the Northwestern states, hard winter wheat in the Southwest, hard and soft

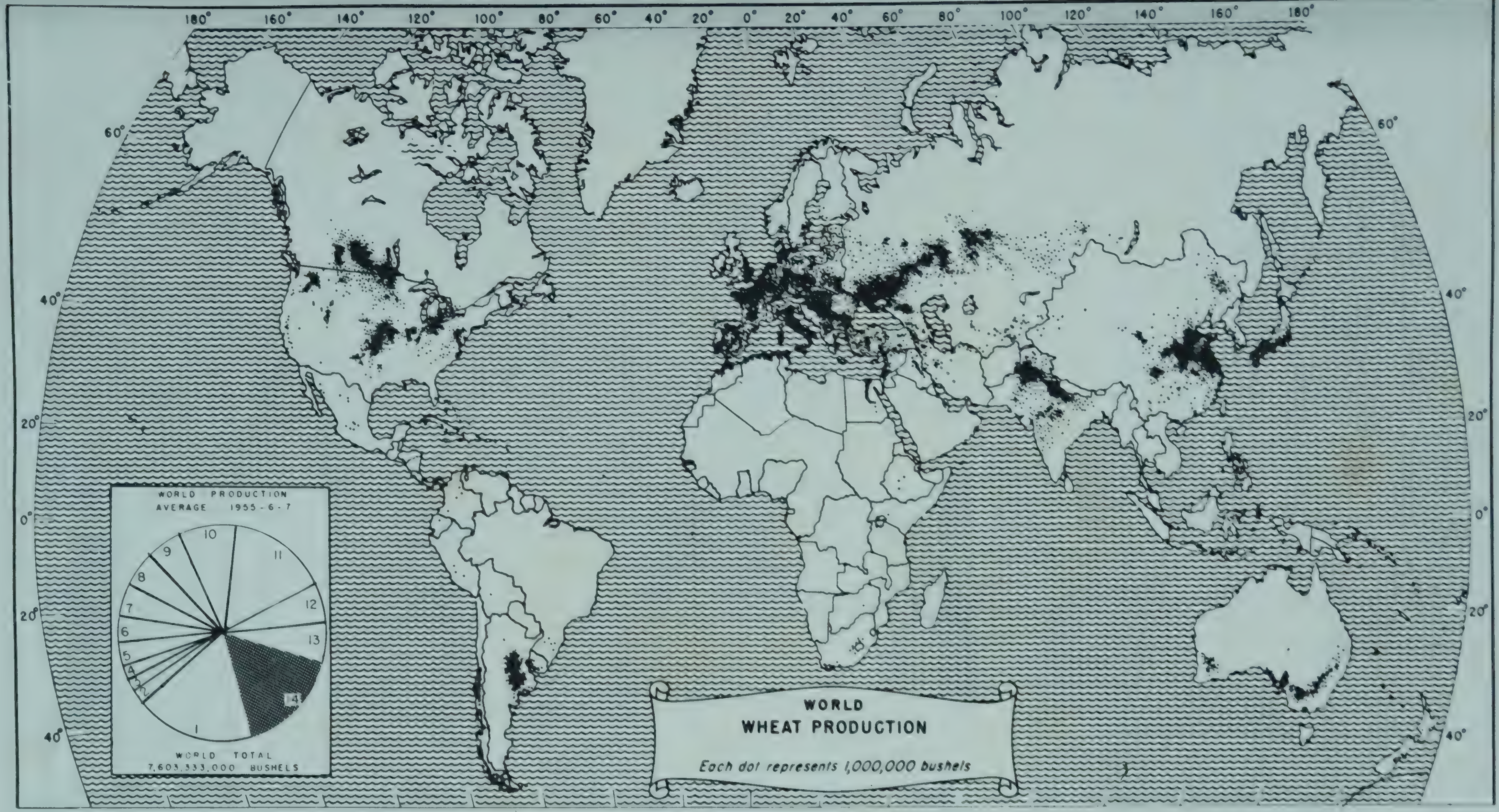
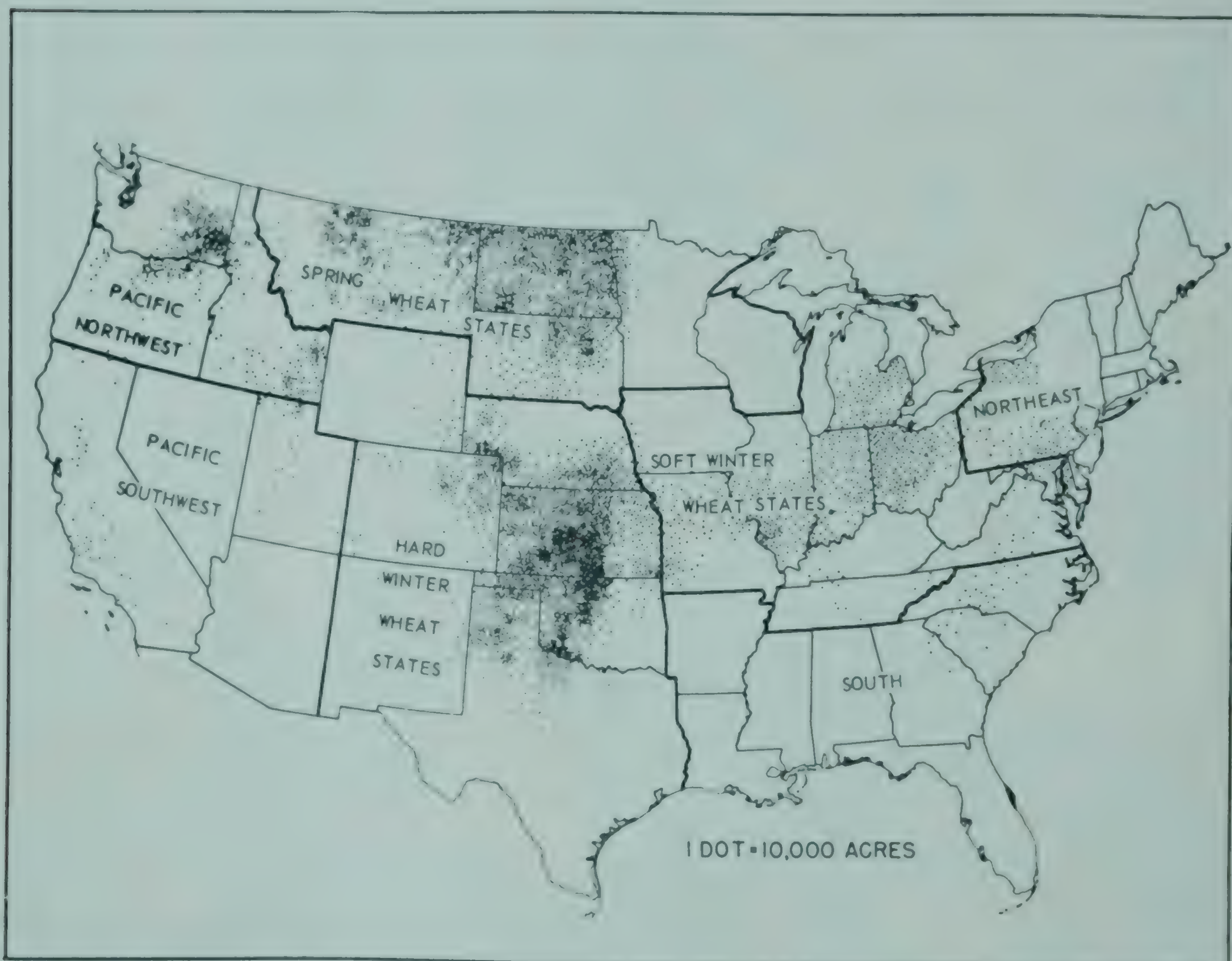


FIG. 8. WORLD WHEAT PRODUCTION

Circle segments show share of world wheat production by countries. 1. U.S.S.R.–19 per cent; 2. W. Germany–2 per cent; 3. Australia–2 per cent; 4, Pakistan–2 per cent; 5. Spain–3 per cent; 6. Argentina–4 per cent; 7. Turkey–4 per cent; 8. France–6 per cent; 9. India–6 per cent; 10. Canada–9 per cent; 11. China–15 per cent; 12. All Others–6 per cent; 13. Italy–6 per cent; 14. United States–16 per cent. Map is based on Foreign Agriculture Service, U.S. Department of Agriculture data. World production figures are based on estimates.

wheat in the Pacific Northwest, soft wheat in the area east of the Mississippi River, and durum wheat in North and South Dakota.

The most rapid expansion of wheat acreage harvested in the United States came at the first part of the present century (Pool 1948). The average harvested acreage between 1899 and 1901 was nearly 51 million and it remained near that until 1913 when, due to World War I, a rapid expansion culminated in planting 73 million acres in 1919. After World War I, the harvested acres of wheat returned to a level near where they were at the start of the century, but acreage increased again during and



Courtesy of U.S. Dept. Agr.

FIG. 9. WHEAT ACREAGE MAP OF THE UNITED STATES

after World War II. The highest harvested acreage was in 1949 and amounted to nearly 76 million acres. Acreage allotments, the Soil Bank, and various governmental efforts to restrict wheat production have reduced the present harvested acreage to well below 50 million acres, but reduced acres do not mean reduced wheat production. On several occasions in past years, total United States wheat production has exceeded one billion bushels. Several years Kansas has harvested 200 million bushels and North Dakota, 150 million bushels, together totaling more

TABLE 4

AVERAGE UNITED STATES WHEAT SUPPLY AND DISTRIBUTION, IN BUSHELS FOR YEARS 1951 TO 1956[1]

Total production	1,077,261,000
Used for seed	75,845,000
Milled for flour	530,622,000
Grain exports	283,018,000
Fed to livestock	75,461,000
Total disappearance	964,946,000

[1] From U. S. Dept. Agr., Agricultural Statistics 1957.

than one-third of the entire production in the United States. South Dakota, Montana, Washington, Texas, Oklahoma, and Nebraska are other large wheat producing states.

The average United States wheat supply and distribution during the years 1951–1956 are shown in Table 4.

PRODUCTION METHODS

Growing the Crop

Farm practices for preparing the seed bed, seeding, and harvesting wheat differ from one section of the country to another. The most critical conditions prevail, usually in the semi-arid Southwest, where land preparation evolves around moisture conservation. The general practices of preparing land for seeding to wheat follow the usual sequence of plowing, disking, harrowing, and drilling. These operations are performed in various ways by common types of equipment. The end result sought is the preparation of the soil for seeding that will result in the highest possible germination of seed and the production of healthy plants.

Hard Red Winter Wheats

It is a general rule throughout the world that wherever winter wheat can be grown, it will be. Planting in the fall, and thus permitting the plant to establish a root system before the dormancy period, makes it possible for the plant to use effectively spring moisture, warmth, and sunshine. There is no spring delay caused by waiting until the field becomes sufficiently dry to cultivate. Thus, except in areas where the loss from winter killing is great, it is common practice to produce winter wheat. In most instances, there are definite quality differences between wheats of winter and spring habit, but that is not the universal rule. There are areas where seasons permit either spring or winter wheat to be grown. For example, in the Pacific Northwest it is customary to sow winter wheat, but if the stand is poor because of winter killing or poor germination due to dryness in the fall, it is possible to re-seed in the

spring, and with favorable weather conditions, produce a spring wheat crop.

Varieties of hard red winter wheat are grown under widely varying environmental conditions ranging from the eastern to the extreme western parts of the United States, and in all but the coldest regions. However, even in areas of extreme cold winter weather, such as in Montana, considerable winter wheat is grown. The southwest states are the principal producers of hard red winter wheat, with Kansas the leading state. Shellenberger (1957) reviewed the history of wheat production in Kansas, the state producing the most wheat.

In many sections of the Southwest where moisture is marginal, it is customary to alternate seeding with a year of nonplanting to conserve moisture. This practice is known as summer fallow. Much of the wheat farming in the Southwest is on very large farms where large equipment is used. Wheat is planted frequently with twelve-foot drills and nearly always deep enough to reach moist soil and thus permit rapid germination. Frequently soil packing equipment is used to prevent too rapid drying of the soil. Call (1914), Martin (1926), Jardine (1916), and Leighty and Taylor (1927) have reported that early plowing and early seeding of winter wheat are usually beneficial. There is considerable use of winter wheat for grazing. This subject has been discussed recently by Anderson (1956).

Hard Red Spring Wheats

Nearly all the hard red spring wheat is grown in the northwest states of Minnesota, North and South Dakota, Montana, Idaho, and Washington. In the drier areas of the western Dakotas, Idaho, and Washington, it is common to summer-fallow to conserve moisture. In the more humid areas, spring wheat is a part of regular crop rotation practices,

It is a general custom to seed spring wheat with a drill as soon as the soil is sufficiently dry to work. Early seeding provides a better opportunity to escape the effects of damage from hot weather, as well as insuring higher yield, as shown by Dungan and Burlison (1942). Spring wheat predominates where winter wheats are killed by severe winters.

Durum Wheats

Amber and red durums are grown in a relatively small area in North and South Dakota and Minnesota. The small quantity of red durum grown usually sells at a discount. Seeding and harvesting practices for durum wheats are the same as for hard red springs.

Although there is a good demand for durum wheat in the United States, farmers are often reluctant to grow durum because of the higher seed

requirements, rough awns, and generally weak straws that may lodge. In addition, the yield per acre of durum wheat averages less than spring and winter wheats. During the past ten year period the yield per acre for durum was 11.7 bushels compared with 14.6 bushels per acre for hard spring wheat and 18.6 bushels for hard red winter.

Soft Red Winter Wheats

These are predominantly the wheats grown in the areas of greater rainfall, roughly east of the Mississippi River. The so-called "corn belt" also corresponds with the region of high production of soft red winter wheat. In fact, it is common to find farms where corn has been cut and winter wheat drilled in corn field stubble. Often wheat can be planted following corn by merely disking and harrowing the land. The use of commercial fertilizers to increase yields is commoner in the soft red winter region than other areas where wheat is grown. In general, soft red winter wheat is grown on smaller, diversified farms.

White Wheats

White wheats may be either spring or winter in habit. Principal areas of production are the western states of California, Idaho, Oregon, and Washington, and in the State of Michigan in the Mid-West and New York in the East. In the United States, most white wheats are soft and have, in general, many of the same characteristics as soft red winter wheats. Cultural practices are about the same also.

HARVESTING WHEATS

Time of Harvesting

As shown in Table 1, somewhere in the world, wheat is being harvested every month in the year. In the United States, harvest starts in early May in Southern Texas, reaches its peak in the hard red winter areas of the Southwest in early June, and ends in October in the northern portions of the red spring wheat area.

Methods of Harvesting

Not many years ago, the common method of harvesting grains was the binder, which is still in use, especially on small farms. Today, to a great extent, combines, small and large, have taken over wheat harvesting. They cut and thresh the crop and are frequently self-propelled. Spring wheat is often wind rowed or swathed before threshing.

From the combines, most spring and winter wheats are taken by truck directly to local elevators where railway cars haul the wheat to terminal

markets. Each year good highways and larger pay loads increase the distances wheat can be hauled economically by truck. Particularly in the "corn belt" area, soft red winter wheat is often stored on the farm, since smaller amounts are produced in that region. Both farm storage and huge cooperative terminal storage facilities are common in the major wheat producing areas.

CLEANING GRAIN

Most grains are not cleaned by either farmers or country elevators. Wheat delivered at an elevator is sampled and graded with considerable accuracy and the elevator operator usually makes a price adjustment on the basis of moisture content, test weight, foreign material, and damaged or broken kernels. It is not usual to clean or blend to regulate grade at small country elevator points; however, where facilities permit, it is often possible to improve grades by properly mixing the grain held in storage. The important reason why wheat is not cleaned once it has been weighed and graded is that to discard any material whatsoever constitutes a weight loss. Normally, whatever material is removed from wheat in the cleaning process has less value than wheat; consequently, cleaning can result in a direct financial loss. The task of cleaning wheat is left to the processor.

Wheat received at terminal elevators may be changed in a variety of ways such as by drying, washing, cleaning, separating, or sizing. Also, various grades and qualities can be collected and blended to supply processors wheat of uniform quality in large quantities.

STORAGE

Storage of cereal grains has been covered fully by Anderson and Alcock (1954). Storage facilities vary from small inexpensive farm-type steel or wooden bins, to elaborate systems involving mechanical ventilation. On farms, the circular type steel bin holding approximately 1000 bushels of grain is popular, while for terminal storage, a single elevator often has a capacity of several million bushels.

Marketing wheat commercially is based on the concept that, when reasonably dry, it can be stored for long periods without undergoing a change in grade. Maintaining large quantities of wheat in safe storage is a tremendously important economic consideration. Wheat is a biological material. It is alive and can deteriorate and die in storage if either the moisture content or temperature becomes too high. Wheat is also subject to attack by micro-organisms, insects, and rodents when storage conditions are inadequate. For safe storage, the following must be con-

sidered: (1) moisture content, (2) temperature of the wheat, (3) infestation, and (4) type of bin.

Storage deterioration can be controlled by drying damp wheat to a safe moisture content and keeping it dry and cool, and by providing good storage structures, and by aeration or forced ventilation. Fumigation will control infestation. There is ample evidence that under normal conditions wheat does not deteriorate with storage age, at least within several years. Shellenberger *et al.* (1958) have shown that the length of storage of wheat has no appreciable influence on the storage properties of the flour milled from the wheat.

When wheat is stored improperly, deterioration is possible from any number of causes, including: (1) insect damage, (2) molds, (3) heat damage, (4) germ damage, (5) sprouting, (6) rotting, and (7) damage by rodents. These factors not only can injure wheat and cause economic loss by lowering germination, but they also can cause actual loss in weight of wheat, bring about undesirable changes in odor, sanitary quality, and nutritive value, and can alter the chemical components such as the proteins, lipids and starch.

Experience, dating from antiquity, and modern research on grain storage have shown that moisture content and temperature are the principal influences in safe storage. The maximum moisture content at which wheat can be stored safely depends on the locality and the length of the storage period. Kelly *et al.* (1942) have shown that wheat may be safely stored for a year with a moisture content about one per cent higher in North Dakota than in Kansas because of the lower average temperatures in North Dakota. For farm-type bins, wheat can be stored for a year or more at a moisture level of 13.0 per cent. Hard wheats can often be kept safely with a moisture content of 14 per cent.

UTILIZATION OF WHEAT IN THE UNITED STATES

Utilization as Human Food

The total utilization of wheat, including food, seed, feed, and industrial use, has increased slightly during the past half century from about 575 million bushels to 625 million bushels. During this period, the population of the United States increased nearly 80 million, or approximately 86 per cent. The per capita consumption of wheat in the United States has declined steadily from 4.1 bushels in 1930 to 2.7 bushels in 1957.

The total quantity of wheat flour used for bread and pastry production by the baking industry in 1954 was 10,379 million lbs., of which 1,723 million lbs. was used to produce biscuits, crackers, and pretzels. Total flour production in 1954 was 22,140 million lbs., including 829 million

TABLE 5

QUANTITY OF WHEAT USED IN BREAKFAST FOODS, UNITED STATES, 1935–57

Calendar Year	Quantity[1]
	1,000 Bushels
1935	8,219
1936	8,866
1937	9,226
1938	9,261
1939	9,381
1940	9,154
1941	9,265
1942	9,360
1943	9,491
1944	9,339
1945	9,439
1946	9,545
1947	9,828
1948	9,811
1949	9,793
1950	9,776
1951	9,758
1952	9,741
1953	9,723
1954[2]	9,705
1955[2]	9,688
1956[2]	9,671
1957[2]	9,652

[1] Includes flour in wheat equivalent.
[2] Subject to revision based on next Census of Manufactures.

lbs. of durum wheat flour. Durum wheat is used almost exclusively for the production of macaroni type products. Statistics on macaroni production show that per capita consumption has increased from 5.1 lbs. to 6.6 lbs. during the past twenty years. Cereal preparations, comprising a variety of products such as breakfast foods, both those to be cooked and those ready to serve, coffee substitutes, cereal baby foods, etc. totaled 1,605,744 lbs. (This total includes cereal breakfast foods made from corn, oats, and other grains in addition to wheat.) The quantity of wheat used in breakfast foods is shown in Table 5.

Feed and Industrial Uses

Traditionally, wheat has been considered a good livestock and poultry feed. It compares favorably with corn in feed value and is superior to barley. However, since the government subsidy programs started in 1947, use of wheat for feed has declined steadly. Except for wheats unsuitable for milling purposes, it generally is not economically feasible to use wheat for feed. In the northeastern and south eastern states, some wheat is consumed as feed on farms and there is some use of wheat in commercially mixed feeds, but generally the high price support program restricts wheat usage for feed purposes.

Industrial uses of wheat amount to more than 1.7 million hundredweight of flour for the manufacture of industrial alcohol, gluten, monosodium glutamate, starch, pastes, and core binder. Some wheat is also malted. Wheat malt is used chiefly to enhance the diastatic activity of wheat flour. Its price, which is higher than that of barley malt, has limited its use by the brewing and distilling industries. Usually clears and low-grade flours are used in the manufacture of wheat starch, monosodium glutamate, gluten, and for pastes in the manufacture of plywood adhesives, book binding, and paper hanging. Wheat products have been used to a small extent in foundries as a core binder in making molds for castings.

IMPORTANCE OF WHEAT TO THE ECONOMY OF THE UNITED STATES

The great adaptability of wheat to varying climates and soils is evident from the fact that wheat is grown in sufficient quantities to be reported in *Agricultural Statistics* (Anon. 1957), in 41 of the 48 states of the Union. Only in the New England states is wheat not an important farm crop.

TABLE 6

WHEAT MARKETING STATISTICS

	Cash Marketing by Farmers in U. S.[1]	Price per Bushel[2]	Cash Value to Farmers in U. S.
1947	$1,187,878,000	$2.29	$2,720,240,620
1948	1,120,370,000	1.98	2,218,332,600
1949	949,842,000	1.88	1,785,702,960
1950	876,808,000	2.00	1,753,616,000
1951	852,665,000	2.11	1,799,123,150
1952	1,170,300,000	2.09	2,445,927,000
1953	1,052,278,000	2.04	2,146,647,120
1954	884,208,000	2.12	1,874,520,960
1955	842,038,000	1.99	1,675,655,620
1956	914,250,000	1.97	1,801,072,500

[1] U. S. Dept. Agr., Agr. Marketing Service, *The Wheat Situation*, June 1957.
[2] U. S. Dept. Agr., Agr. Marketing Service, *The Wheat Situation*, February 1958.

In 1957, even with the efforts being made to restrict production, 947 million bushels of wheat were produced in the United States on 43,664,000 harvested acres and the 1958 crop estimate is nearly 1.5 billion bushels. Normally, the principal wheat producing states are Kansas, North Dakota, Montana, Oklahoma, Nebraska, and Washington.

Although there can be considerable variation from year to year, at present total stocks of wheat in the United States are estimated to be 1,377,393,000 bushels distributed as follows: on farms, 291,629,000 bushels; at terminal markets, 360,662,000 bushels; held by commodity credit corporations, 72,516,000 bushels; held by flour mills for processing, 652,

586,000 bushels. Out of this stock, it is estimated that 50,000,000 bushels will be used for seed, 550,000,000 bushels milled into flour, and roughly 300,000,000 bushels exported.

The importance of the wheat industry to the United States' economy is evident. The sale of wheat is an important source of farm income (Table 6).

Transporting, handling, financing, and storage of wheat involve the cross section of the United States' business activities. In addition, the processing of wheat represents a tremendous industry. In fact, wheat is a world symbol for food and provides economic and political stability for millions of people. Of all cereal grains, wheat is the one that enters most into international trade.

COMPOSITION OF WHEAT

The composition of wheat varies greatly from area to area and from year to year within a given area. The possible range of variability of composition of wheat in the United States in a crop year is indicated in Table 7.

TABLE 7

APPROXIMATE COMPOSITION OF WHEAT

Determination	Composition Range	
	Low	High
	Per cent	Per cent
Protein (N × 5.7)	7.0	18.0
Mineral matter (ash)	1.5	2.0
Lipids (fat)	1.5	2.0
Starch	60.0	68.0
Cellulose (fiber)	2.0	2.5
Moisture	8.0	18.0

Hard red spring or winter wheat usually has a protein content of at least twelve per cent. Soft red or white wheats for cake and cookie flour manufacturing are weak and possess protein contents from 8 to 10 per cent. Wheats that are between the bread and pastry types are used for cracker, doughnut, and all-purpose flours.

In addition to the approximate composition of wheat, which includes only the broad chemical constituents, a vast amount of analytical data has been assembled on the amino acid content of the wheat proteins, the composition of the mineral matter, enzyme components, vitamin content, and the properties of the starch and other carbohydrate material. Bailey (1944) has presented the significant facts and data relating to the sub-

stances present in wheat. More recent information on this subject has been covered by Jacobs (1951).

QUALITY TESTS

Physical Tests Applied to Wheat

Miller and Johnson (1954) have reviewed tests used for the evaluation of wheat quality. They list the following physical tests which are commonly applied to wheat:

1. Federal grade, which includes test weight.
2. Kernel hardness.
3. Gluten washing.
4. Internal infestation.
5. The milling test.

Methods for performing these physical tests are included in the hand book of the Official Grain Standards of the United States (Anon. 1957B) and Cereal Laboratory Methods (Anon. 1957A).

TABLE 8

STANDARDS FOR WHEAT

Grade	Minimum Test Weight Per Bushel	Maximum Limits of: Damaged Kernels: Total	Damaged Kernels: Heat Damaged Kernels	Foreign Materials	Wheat of Other Classes[1]
	Lbs.	Per cent	Per cent	Per cent	Per cent
1	60	2	0.1	0.5	5
2	58	4	0.2	1.0	5
3	56	7	0.5	2.0	10
4	54	10	1.0	3.0	10
5	51	15	3.0	5.0	10
Sample grade					

Sample grade: Does not meet requirements of grades 1 to 5 or which contains more than 16 per cent moisture, or stones, or is musty, sour, has heated, or has objectional odors except smut or garlic or which contains so much smut that a standard grade does not apply.

[1] Limitations are put on the amounts of other classes of wheat that are present.

Official grades of wheat include seven categories, namely, Hard Red Spring, Durum, Red Durum, Hard Red Winter, Soft Red Winter, White, and Mixed Wheat. Within each class, test weight, percentage of hard and vitreous kernels, extent of damaged kernels, and amounts of foreign material and wheats of other classes determine the sub-class and numerical grade. These factors are summarized in Table 8. Determining the grade is the first step in the appraisal of wheat quality and is the domi-

nant consideration in marketing and handling wheat. Moisture and protein content information usually are considered along with the grade and also the extent of infestation, especially when wheat is evaluated for processing.

Milling quality is a broad term used to embody the many factors that affect the milling process. Among them are the response of the wheat to conditioning, the millability or reduction of stocks, and the flour yield. Many attempts have been made to standardize and evaluate experimental milling procedures but progress has been slow. Hard, soft, and durum wheats respond in vastly different ways to milling operations.

The gluten washing test is a physical determination of quality once applied generally to wheat in the United States, but now replaced almost entirely by the protein test. The gluten test is, however, in use in many places in the world. Essentially the test involves removing starch from a flour-water dough and collecting a cohesive mass of gluten which can be evaluated both as to quantity and quality. Weaknesses of the gluten test are the lack of reproducibility and the differences in interpretation of gluten quality.

Chemical Tests Applied to Wheat

Moisture, ash, and protein tests are the most widely used tests performed on wheat. The Kjeldahl protein test normally is made on all hard wheat reaching terminal markets but it is not an official part of the U. S. Grain Standards. This test provides supplementary information to that given on the grade certificate. To report protein content on a uniform moisture basis, the moisture test is necessary. Miller and Johnson (1954) state that moisture is related to quality of wheat and flour in at least three ways, namely: (1) flour yield varies inversely with moisture content; (2) composition percentages are inversely related to percentages of moisture present; and (3) deterioration of grain during storage may depend on the moisture relationships in the wheat kernel.

The ash test is significant as a way to determine flour grade. Since the ash content of bran is about 20 times that of endosperm, the ash test indicates the thoroughness of the separation of bran and germ from the kernel endosperm. There is considerable variation in the amount of mineral matter in wheat, depending on the class of wheat and the area where grown; therefore, the ash test is often applied to wheat as well as to flour.

Color tests, such as the Pekar or the slick test, are also used to judge milling results or flour grade, and recently photoelectric methods (Kent-Jones and Martin 1950) for assessing flour color have come into use.

Attempts have been made to appraise wheat quality on the basis of the amino acid composition of wheat gluten. To determine the amino acid

composition of wheat is a long, tedious, and expensive procedure, and recent work (Pence *et al.* 1950) has failed to show essential differences in the amino acid content of 17 flours milled from different varieties and types of wheat.

Physical-Chemical Tests

A large number of tests based on the imbibitional properties of the wheat proteins have been developed and used. Berliner and Koopman (1929) evolved a method to measure the swelling power of gluten. Gortner (1924) and his co-workers did much to develop and popularize the use of the viscosity test as a measure of flour quality. Zeleny (1947) presented a simple sedimentation test which has been proposed as a method to estimate the baking quality of wheat. The method consists essentially of suspending flour particles in a graduated cylinder containing dilute lactic acid. The rate of sedimentation is a measure of the hydration capacity of the flour proteins and is an index of quality. The sedimentation test applied to approximately 360 cargos of wheat in world commerce by Shellenberger (1958) showed a correlation of 0.726 between sedimentation values and the over-all quality score of the wheats. This was a significantly higher correlation than that between protein content and quality score.

Many investigators have attempted to use the heats of hydration of wheat flour as an index of quality. The method thus far has not proved practical since the differences in the values between flours of known different properties are slight. Peptization and gluten fractionation methods as a means for measuring gluten quality also have not proved useful.

Gas production and gas retention measurements in dough have been developed to measure automatically gas production and gas retention. This evaluation of data and the relation to flour quality form an important determination.

Varietal Differences in Gluten Quality

Many techniques have been developed to separate gluten from the other constituents of wheat flour. The washing-out process can be done by hand or mechanically. A quantitative test consists merely of weighing the gluten either wet or after being dried, but the estimation of gluten quality is a more difficult matter.

The measurement of gluten quality has been based on four general principles, namely: expansion by heat, recovery from compression, gluten extension and gluten relaxation. The more satisfactory methods for appraising quality are those that use the extension or relaxation of gluten.

Although there is agreement that many properties of dough are due to

the gluten component of flour, most cereal chemists in the United States prefer to study the properties of doughs rather than face the problem of separating gluten and attempting to appraise quality by this means. Regardless of the methods used, differences in gluten properties between classes and varieties of wheat are obvious.

The meaning of quantity of protein in wheat or flour is readily understood since determining protein is a standardized procedure. The meaning of gluten quality is not parallel because quality is fixed by the characteristics inherent in the wheat kernel and by the purposes for which the flour is to be used. There are three well defined gluten ranges: strong hard wheat gluten, weak soft wheat gluten, and durum type gluten, the last being poor for bread dough but ideal for macaroni products.

Varieties within the classes of hard red spring, hard red winter, or hard white wheat can possess wide differences in gluten quality. To be of top quality, a variety of hard wheat should possess a high dough absorption, have wide mixing and fermentation tolerance, and be capable of producing bread of good volume, grain, and texture. Some wheat varieties possess these necessary attributes to a high degree while others do not. The selection of satisfactory wheat for specific purposes depends upon the determination of this gluten quality.

Quality Tests for Milling Wheat

Wheat is marketed on the basis of the Federal Grade. The dominant factor affecting grade, after the class has been established, is test weight. If wheat is designated as "tough," it means that it has a moisture content between 14 and 15.5 per cent, if it is soft wheat, and between 14.5 and 16 per cent, if it is hard wheat. In addition to test weight, determining grade is based on the extent of damaged kernels and the amount of foreign material and wheats of other classes. All of these factors constitute an effective means to describe wheat for marketing purposes; however, a great deal more about wheat needs to be known when it is purchased to manufacture specific types of flour.

The grade of a wheat indicates its freedom from foreign materials and the probable cleaning loss involved in preparing the wheat for milling. At the lower test weights, especially, there is some relation between flour yield and test weight. Therefore, the first appraisal of wheat quality for processing is obtained from knowledge of the official grade.

Tests for protein, moisture, and ash are commonly applied at one time for the evaluation of wheat for processing purposes. The protein test is the best single test that can be applied to estimate quality. Nevertheless, this estimation is far from satisfactory, because no one test can be expected to be suitable for the quality appraisal of a complex biochemi-

cal system like the one in a wheat kernel. Yet, the correlation between protein content and quality is high. Low protein content in wheat indicates quality for cake and pastry flour, while high protein points to bread flour use.

The moisture determination is useful in considering storage and conditioning requirements. The ash determination need not necessarily be considered a part of the essential quality information. If wheat is purchased from an area where the mineral content in the kernel is unusually high, then it is advisable to have a record of the wheat ash.

To obtain a satisfactory insight into wheat quality, it is necessary to mill the wheat and subject the flour obtained to tests not only of protein quality but also of baking strength. The Brabender (1932) farinograph is one of the most commonly used instruments to measure absorption and physical dough properties of wheats. This instrument measures the plasticity and mobility of dough when subjected to mixing at a constant temperature. Although the farinograph is useful to estimate absorption and dough development properties of both hard and soft wheat flour, it has greater utility for hard wheat. The viscosity test (Bayfield 1934) is used extensively to appraise soft wheat quality.

Wheats destined for milling purposes are often subjected to indirect measurements for amylase activity by means of gas production or use of the amylograph. (Anon. 1957A). Most hard wheat flours require the adjustment of the amylase level, but wheats unusually high or low in amylase activity require special consideration for use in mill blends.

In North America it is common for the milling industry to have an accurate estimation of the baking quality of the wheats used to make up the mix. Standard type tests have been developed to help appraise quality of bread, cakes, and pastry products. The experimental bread baking test has reached a high state of acceptance as a measure of wheat quality. The real appraisal of wheat quality is based on its use.

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Corn

INTRODUCTION

Origin

Corn (*Zea mays* L.) or maize originated in the Western hemisphere. It was the only cereal systematically cultivated by the American Indian although some other grains were harvested from the wild state. Columbus found corn being cultivated on Haiti, where it was called mahiz. From this Arawak Indian word was derived the name maize that is used in Europe to distinguish the cereal from other grains which are called "corn" (Hunt 1915).

The origins of corn are lost in antiquity, but the earliest samples which have been identified were by their nature incapable of independent existence. Many thousands of years of crude selection must have been exercised to bring the plant to this point from its native wild form.

The tribe Tripsaceae to which corn belongs differs quite widely from the tribe Hordeae, to which the other common cereal grains wheat, rye, and barley belong. In the same tribe with corn are teosinte (*Euchlaena mexicana* Schrad.), a subtropical plant regarded by some as the ancestor of corn, gama grass (*Tripsacum dactyloides* L.), and adlay or Job's tears (*Coix lacryma-Jobi*).

Corn can be readily crossed with teosinte and some of the hybrids are even fairly fertile, indicating the close relationship of these two plants. However, some botanists consider *Zea* to be the older of the two genera, teosinte having arisen (according to their views) from a relatively recent cross of corn with gama grass. This theory is well supported by genetic evidence. Still other authorities (Weatherwax 1954) favor the hypothesis that corn, teosinte, and tripsacum evolved from a single ancestral stock by ordinary divergent evolution. The various hypotheses of the origin of corn are well summarized by Wallace and Brown (1956).

Distribution of Production

More corn is produced in the United States than in all of the rest of the world combined, Russia excepted. The latter country has been emphasizing maize production in recent years, expending much effort on growing this grain in various unsuitable locales—apparently for ideological rea-

Courtesy of U.S. Dept. Agr.

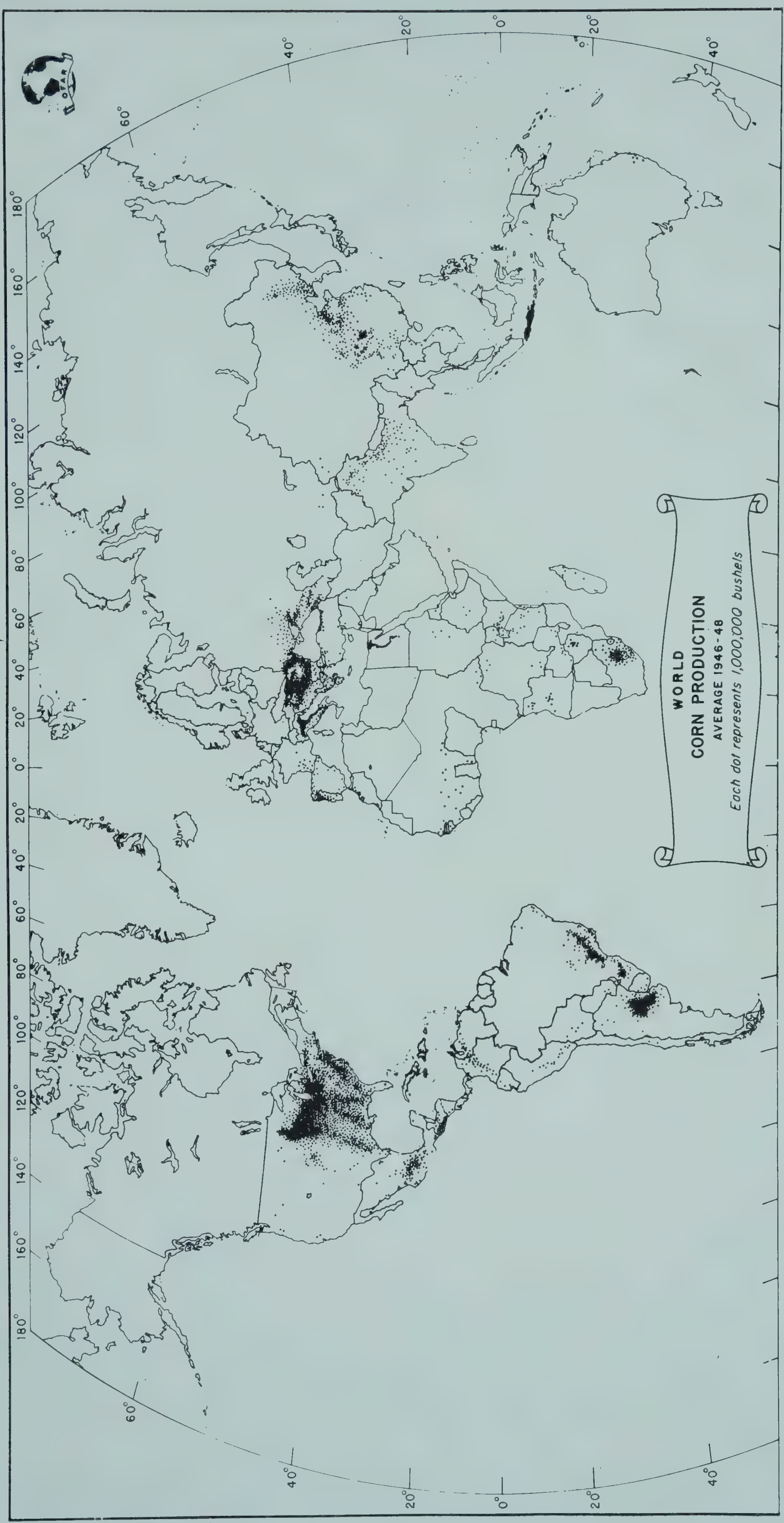
Fig. 10. *Euchlaena mexicana*

Courtesy of U.S. Dept. Agr.

FIG. 11. *Zea mays*

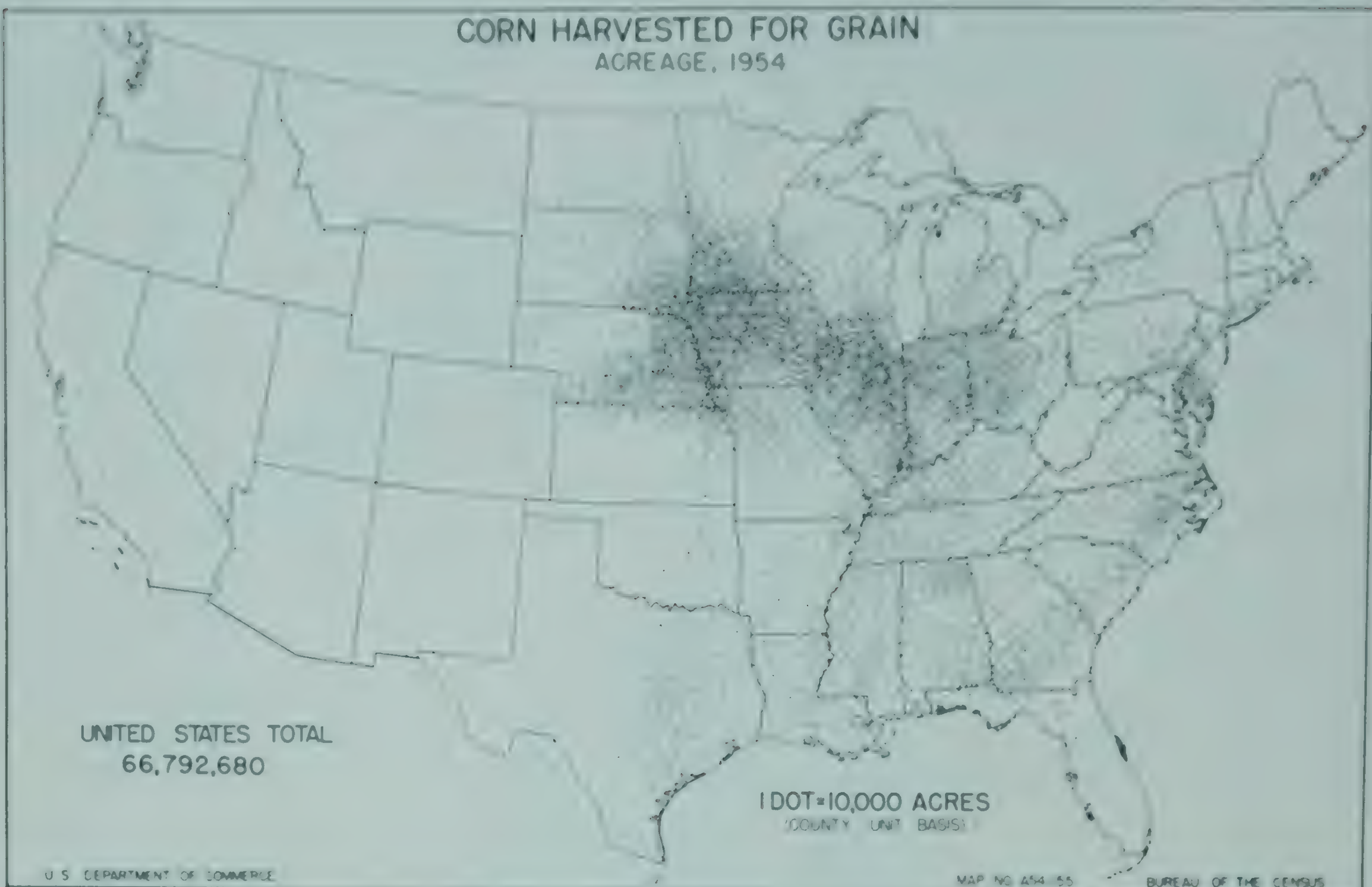
sons. The figures on Russian production are rather unsatisfactory for several reasons, and are not included in world estimates. In 1957 the world total was 6.6 billion bushels and the United States total was 3.4 billion bushels. Recently, the United States production has decreased due to marketing restrictions, but world production has been climbing steadily for many years.

Iowa and Illinois vie for top honors in annual corn yields. No other state produces half as much as either of them. All states report some corn



Courtesy of U.S. Dept. Agr.

FIG. 12. WORLD CORN PRODUCTION



Courtesy of U.S. Dept. Commerce

FIG. 13. CORN HARVESTED FOR GRAIN IN THE UNITED STATES

grown, although Maine, New Hampshire, Rhode Island, Nevada, and Alaska produce less than a million bushels annually of corn grown for all purposes.

FACTORS AFFECTING YIELD AND QUALITY

Soils and Climate

Corn can be grown in a wide variety of climates and on very diverse kinds of soils as indicated by the geographical distribution of its production. However, it requires deep, dark, silt loam, good drainage, abundant moisture, and moderately high temperatures for maximum yields.

Sandy soils are less suitable for production of corn because they do not retain moisture for a sufficient length of time. In addition, sandy soils often contain low concentrations of essential nutrients. The latter condition can, of course, be corrected temporarily by fertilization, but excessive leaching of the fertilizer by rainfall may make this practice uneconomical. Clay soils also give relatively low yields because they are liable to be too compact to allow maximum root proliferation and may have inadequate drainage.

Bates (1955) showed that the mean maximum temperature, the mean relative humidity and the evaporation in June (the month in which corn is

usually pollinated in the region where Bates conducted the experiments reported by him) were very closely correlated with corn yields. Each of these three factors was more closely correlated with corn yields than was rainfall at any period of the year. The number of rains in June showed a higher correlation with yield than did any other rainfall factor. The rather indirect relationship of rainfall in any short period to yield may be partially explained by data of Russell and Danielson (1956), who showed that corn utilized water to a depth of five feet or more in a deep Brunizem soil in Illinois, while rainfall and irrigation affected the soil moisture profile to a depth of only two feet on both corn and fallow plots. Letey and Peters (1957) showed that corn yields were closely related to the reserve soil moisture conditions at the beginning of the growing season and to the soil moisture stress to which the plant was subjected during the growing season. The moisture stress effect on growth was found to be closely related to the seasonal weather. The efficiency of water use was found to be strongly conditioned by soil temperature.

Gingrich and Russell (1956) found that both the soil moisture tension and the oxygen concentration of the root atmosphere had important effects on growth.

Willis *et al.* (1957) grew corn seedlings in temperature controlled greenhouses and in field plots where the temperature was adjusted by underground heating cables. In the average soil temperature range tested, 60° to 80° F., the rate of corn growth seemed to be approximately in accordance with the Van't Hoff law, the Q_{10} of the law being from 2.0 to 2.8. The most favorable soil temperature at the four-inch depth for corn grown in central Iowa appeared to be about 75° F. The time between silking and maturity was reduced by increased soil temperature.

Corn is grown in many areas where the temperature and soil requirements for optimum yield are not found. Use of hybrids selected to fit the limitations of the soil and the climate where optimum conditions do not exist, tends to reduce, but does not eliminate, the decrease in yield resulting from these limitations. Proper selection of planting time, to take advantage of a soil temperature of at least 60° F. is also helpful, but this procedure has obvious limitations.

Rotation and Fertilizer

Corn extracts enormous quantities of nutrients from the soil. In fact, it is the cereal crop most destructive to soil fertility. Millar and Turk (1951) indicate that a 50-bushel per acre corn crop removed from each acre of soil 78.4 lbs. of nitrogen, 27.6 lbs. of phosphorus, 55.2 lbs. of potassium, 14.7 lbs. of calcium, and 5.6 lbs. of magnesium. For this reason, heavy fertilization is essential if corn is to be grown several years in succession on

the same acreage. On the Morrow field plots of the University of Illinois (De Turk *et al.* 1927), where corn has been grown continuously since 1888, the yield has shown a steady (though uneven) decrease through the years, falling from an initial value of about 54 bushels per acre to about 24 bushels per acre. When oats were grown in alternate years, corn production held up slightly better, showing a decrease from about 50 to about 28 bushels per acre. A corn-oats-clover rotation gave much better results, with only a slight decline throughout the test period. The corn-oats-clover pattern, together with applications of manure and phosphated lime actually showed a significant increase in yield during the earlier years and subsequent maintenance of production at a high level.

Chen and Arny (1941) studied yields of corn grown continuously for 30 years on plots at St. Paul, Minnesota. The figures are somewhat erratic, but show that yields near the end of the study were not much different from the earliest figures when the plots were manured at the rate of two tons per acre per year.

Richer (1950) analyzed results of fertilizer applications on plots where a corn, oats, wheat, and hay rotation had been maintained since 1881. Some of his conclusions were: (1) lime alone does not increase yields; (2) high yields can be maintained indefinitely with inorganic commercial fertilizers; (3) manure should be reinforced with superphosphate; and (4) fertilizers alone cannot compensate for the deficiency of an acid soil, but the addition of lime can increase the efficiency of fertilizers on these soils up to 300 per cent as measured by yield.

Lang *et al.* (1956) showed that the protein content of the kernels of corn increased with increasing nitrogen supply in the soil. The oil content also appeared to increase slightly with added fertilizer. Prince (1954) showed that, under the conditions used by him, there was a direct relationship between the amount of nitrogen applied to the soil and the contents of crude protein, zein, and leucine in the grain. Increasing the rate of nitrogen resulted in an increased percentage of leucine in the grain and in the crude protein. On the other hand, increasing the plant stand decreased the total leucine content. This decrease in leucine content was not proportionately as great as the decrease in crude protein. Therefore, the net effect was to increase the percentage of leucine in the protein. There was not much effect on tryptophan content of nitrogen application or of population. Prince concluded, "The variation in content of the amino acids discussed above suggests that N fertilization in relation to plant population, as well as variety, has an important effect on protein composition." On the other hand, Zuber *et al.* (1954) found that application of 50 lbs. of nitrogen under certain conditions actually resulted in a lowering of the protein content of the grain although protein content of the stover increased. Evi-

dently, conditions must be properly chosen if grain of higher protein content is to result from applications of nitrogenous fertilizers.

Population

It might be expected that grain yield would reach a peak and then decline as the plant population per unit area was increased. This effect does exist, at least under some conditions. Haynes and Sayre (1956) planted corn in rows 8-and-one-half feet apart to reduce row competition to a low level, and then varied the within-row spacings of plants. There was little difference between total plant weights per acre as the within-row spacing was varied from 1 to 4 inches, but the closer spacings increased the stover to ear ratio. Ear corn yield per acre was greatest at a plant spacing of about four inches. Genter *et al.* (1956) showed that planting at 16,000 per acre resulted in higher protein content of the grain than did planting at 10,000 plants per acre. Oil content of the kernels was virtually the same at both levels of population.

Duncan (1958) found that the log of the average yield of individual corn plants making up a population bears a linear relationship to the population, at least between about 5,000 and 25,000 plants per acre. Therefore, only two yield population values are needed to estimate yields at any other population within the linear range. He developed the following equation for estimating maximum yields:

$$Y_{max} = -\frac{0.60\, y_1(P_1 - P_2)}{\left(10^{\left(\frac{P_1}{(P_1 - P_2)}\right)\left(\log \frac{y_1}{y_2}\right)}\right)_{\left(\log \frac{y_1}{y_2}\right)}}$$

where y_1 represents the yields at population P_1, etc.

Where phosphorus and potassium were not limiting, Thomas (1956) found that the average weight of the ears of corn decreased as the planting rate was increased, and this trend could not be reversed by the application of nitrogenous fertilizers.

Weeds and Insects

Weeds compete with the crop for moisture, nutrients, and solar energy. Vengris *et al.* (1955) found that weeds competed strongly with corn at all rates of fertilizer (N, P, or K) application, and suppressed growth and yield of corn. They stated "The feasibility of maintaining high corn yields in the presence of competing weeds by increasing the rate of fertilization is strongly questioned." Certain weed species were much more adversely affected by inadequate essential nutrients than was corn. Thus, in some instances, corn with weeds yielded better when no fertilizer was applied.

Staniforth (1957) found that this did not apply to mature yellow foxtail (*Setaria lutescens* (Weigl)) infestations. Applications of 0, 70, and 140 lbs. of nitrogen per acre resulted in reductions of 14, 10, and 5 bushels per acre from the yield in uninfested plots. Corn yields were increased 2 to 3 times more than the foxtail by fertilizer applications.

The deleterious effect of insects on corn yield and quality can be manifested at any stage in the growth of the plant and in mature ears of corn. This subject is treated in detail in a subsequent chapter. Good discussions may also be found in Wilson (1955) and in Wallace and Bressman (1949).

Varieties

Hybrids, which constitute the majority of corn seed now used in the United States, vary considerably in their growth rate, resistance to disease and insects, ratio of stover to ear, etc. It is evident, therefore, that the hybrid selected for seed will have a considerable effect on the yield per acre. Wilson (1955) gives an extensive discussion of these considerations.

Growing conditions usually seem to have more effect on the protein content of the kernel than does the variety. However, the variety is more important in determining the oil content. Genter *et al.* (1956) studied nine hybrids subjected to variations in location, fertilizer, and rate of planting. They found that of these variables only the hybrid had any significant effect on the oil contents of the kernels. In this series, oil contents ranged between 3.7 and 4.9 per cent, with a mean of 4.2.

BOTANY OF CORN

Classification

Like the other plants discussed in this volume, corn belongs in the family **Gramineae.** Members of this botanical group have fibrous root systems, alternate leaves, two-ranked parallel veins in the leaves, split leaf sheaths, cylindrical stems with solid nodes, and flowers in more or less chaffy spikelets.

The appropriate tribe is the Tripsaceae (Maydeae) and includes not only corn but teosinte, gamagrass, adlay, and some other less well known genera. A distinguishing characteristic of the Maydeae is the presence of male and female flowers in separate spikelets on the same plant. This tribe is similar to the sorghum group Adropogoneae from which it differs principally in the suppression of certain floral parts.

The genus *Zea* has the pistillate spikes grown together forming an ear, the grains at maturity much exceeding the glumes. According to the most prevalent taxonomic view, only one species, *mays*, is included in the genus.

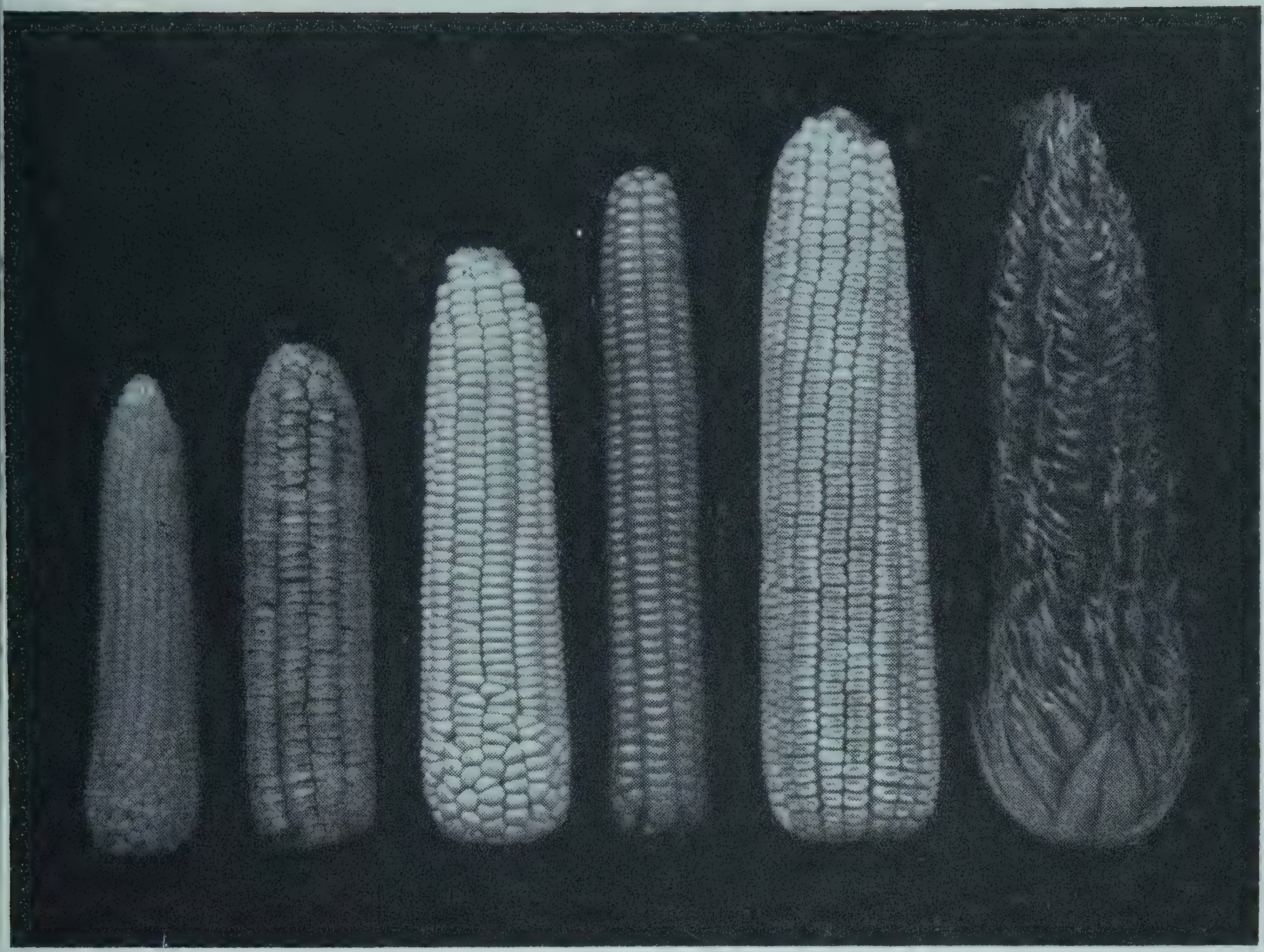


Photo by H. S. Garrison, Courtesy of U.S. Dept. Agr.

FIG. 14. TYPES OF CORN—REPRESENTATIVE EARS OF POP, SWEET, FLOUR, FLINT, DENT, AND POD CORN.

Some taxonomists have been of the opinion that several species, or at least subspecies should be included in this genus. For example, Sturtevant classified sweet corn as *Zea saccharata*, and elevated other types to the level of species.

The major varieties of corn are pod corn, flint corn, dent corn, sweet corn, popcorn, flour corn, and waxy corn. All of these types have the normal 2 *n* chromosome number of 20. The characteristics rendering the variety distinguishable are usually endosperm differences dependent upon the operation of a single gene. For example, the "sweet" phenotype depends upon a single recessive gene.

Pod corn is presumably a primitive type from which modern maize is derived. Each kernel is enveloped by a fibrous husk. This character can appear in any of the other corn types described here.

Flint corn has very hard kernels, as the name indicates. The texture is due to a rather thick layer of hard starch and protein just under the bran layer. Most flints are early maturing and have a certain popularity for this reason. The texture may adversely affect their value for feeding livestock, but presumably does not detract from their milling quality.

Dent corn comprises the largest corn crop in the United States. The crown of the kernels exhibits a pronounced concavity at maturity due to shrinkage of the endosperm as moisture is lost.

Sweet corn and popcorn will be described in later sections of this chapter.

Flour corn is grown in South and Central America to a considerable extent. The grains are large and soft, and the endosperm is very friable. These characteristics permit easy grinding of the grain into flour.

Waxy corn does not contain wax as such but owes its texture to the presence of large amounts of the amylopectin fraction of starch. It is assuming increasing importance due to the industrial uses which are being found for waxy starch.

Description of the Plant and Its Seed

Zea is a robust, erect annual grass. It may reach 15 or more feet in height, though certain varieties rarely exceed one-and-one-half feet at maturity. The plant has broad leaves arranged in two vertical ranks. The inflorescences are monoecious. The flowers of the staminate tassel are borne in many spike-like racemes which together form large spreading panicles which terminate the stems. A pistillate inflorescence is borne on one or more spikes of the leaves. There are eight or more rows of spikelets on a greatly thickened axis (cob) and the whole is inclosed in foliaceous bracts (husks). Protruding from the tops of these bracts are the styles called silks. The styles are long and slender and may be fertilized throughout their length. Except in pod corn, the floral bracts on the axis do not envelope the kernels. The spikelets are unisexual. The pistillate spikelets occur in pairs, both members of which may be fertile, or, usually, one member is fertile and one is sterile. The glumes are broad and rounded at the apex. Lemma and palea are present. Staminate spikelets are two-flowered and are arranged in pairs on the side of a continuous rachis, one member of the pair being sessile and one pedicillate. The glumes are membranaceous, acute, and covered with short hairs. Hyaline palea and lemma are present (Hayes *et al.* 1934).

Wolf *et al.* (1952, 1952A, 1952B, and 1952C) report an intensive investigation of the structure, macroscopic and microscopic, of the corn kernel. In their introduction, these investigators say "The kernel of corn is a fruit composed of a thin pericarp enclosing a single seed. The pericarp is the mature ovary wall and comprises all of the outer cell layers down to the seed coat. Along its inner surface, it adheres closely to the seed coat. The latter in turn encloses the germ and the endosperm, the three forming the seed. This type of single-seeded fruit, in which the pericarp does not

TABLE 9

COMPOSITION OF CORN AND CORN PRODUCTS[1]

Composition, Per cent[2]

Product	Moisture[3]	Protein	Fat	Carbohydrate Total	Carbohydrate Fiber	Ash
Sweet corn, white or yellow:						
Raw	73.9	14.2	4.6	78.5	3.1	2.7
Cooked	75.5	11.0	2.9	82.4	4.5	3.7
Canned:						
Solids and liquid	80.5	10.3	2.6	82.6	4.1	4.6
Drained solids	75.5	11.0	2.9	82.4	4.5	3.7
Frozen	78.0	14.6	4.1	78.7	3.2	2.7
Mature	9.3	12.7	8.7	74.0	2.6	2.0
Popcorn:						
Unpopped	9.8	13.2	5.2	80.0	2.3	1.7
Popped, unseasoned	4.0	13.2	5.2	79.9	2.3	1.7
Field corn:						
Flint	11.5	11.1	4.9	81.6	2.2	1.7
Dent	13.0	10.2	4.6	81.3	2.3	1.5
Corn cobs	9.6	2.5	0.4	59.7	35.5	1.8

[1] Watt and Merrill (1950).
[2] Moisture-free basis.
[3] As is basis.

open on drying to liberate the seed, is characteristic of the cereal grains. It is known as a caryopsis."

Gross appearance of the corn kernel shows a division into the three parts indicated by a diagram in the chapter on **Wet-Milling.** These are the thin outer bran coat, the germ, and the endosperm. Chemically, the bran coat is characterized by a high percentage of fiber, the germ by a high oil content, and the endosperm by a high percentage of starch.

The germ, which in hybrid dent corn constitutes about 12 per cent by weight of the kernel, contains 35 per cent oil. The endosperm, 82 per cent of an average kernel, contains 12 per cent protein and 85 per cent starch and other carbohydrates except fiber. The bran, when separated by methods of high efficiency, is found to represent about 6 per cent of the grain, and to contain 2 per cent oil, 7 per cent protein, 73 per cent starch and other extractable carbohydrates, and 16 per cent fiber.

Although the three major fractions of the grain appear on casual examination to be rather cleanly divided, they are not easily separated in processing. For example, if degerming and oil recovery were 100 per cent efficient, about 2.3 lbs. of oil would be recovered from the embryos obtained from a bushel of corn. In practice, only about 70 per cent of this amount can be recovered in wet milling and only about 28 per cent from dry milling. This low rate of efficiency is said to result from the presence of a "cementing layer" between the endosperm and the germ (Wolf *et al.* 1958) which prevents the easy separation of the two components.

TABLE 10

DISTRIBUTION OF THE CHEMICAL CONSTITUENTS OF CORN[1]

Fraction[2]	Proportion of Whole Grain	Ash	Protein[3]	Oil	Starch	Sugar
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Endosperm portion:						
Average	81.9	0.31	9.4	0.8	86.4	0.64
Range	79.7–83.5	0.22–0.46	6.7–12.8	0.7–1.1	83.9–88.9	0.47–0.82
Germ portion:						
Average	11.9	10.10	18.8	34.5	8.2	10.81
Range	10.2–14.1	9.16–11.3	17.3–20.2	31.1–38.9	5.1–10.0	9.87–12.51
Bran portion:						
Average	5.3	0.84	3.7	1.0	7.3	0.34
Range	4.4–6.2	0.29–2.00	2.9–4.6	0.7–1.2	3.5–10.4	0.19–0.52
Tip cap portion:						
Average	0.83	1.55	9.3	3.8	5.3	1.54
Range	0.8–1.1	1.43–1.95	9.1–10.7	3.7–3.9	....	1.44–1.61

[1] Earle *et al.* (1946).
[2] Field corn, including flint, dent, and flour types.
[3] N × 6.25.

QUALITY OF CORN

Standards

The market quality of field corn is established by referring to standards published by the Department of Agriculture (Anon. 1957). According to these standards, corn is any grain consisting of 50 per cent or more of shelled corn of the dent or flint varieties containing not more than ten per cent of other grains for which standards have been established under the provisions of the United States Grain Standards Act.

Color of the grain furnishes the basis for three fundamental market classes for corn. Yellow corn includes all varieties of yellow and may not include more than five per cent by weight of kernels of other colors. A slight tinge of red on kernels which are predominantly yellow shall not affect their classification as yellow corn. White corn must contain at least 98 per cent by weight of white kernels. Grains showing slight tinges of light straw color or of pink shall be graded white. Mixed corn includes lots of corn not falling into the classes of white or yellow.

TABLE 11

STANDARDS FOR YELLOW CORN, WHITE CORN, AND MIXED CORN[1]

Grade	Minimum Test Weight Per Bushel	Maximum Limits			
		Moisture	Cracked Corn[2] or Foreign Material	Damaged Kernels: Total	Damaged Kernels: Heat Damaged
	Lbs.	Per cent			
1	54	14.0	2	3	0.1
2	53	14.5	3	5	0.2
3	51	17.5	4	7	0.5
4	48	20.0	5	10	1.0
5	44	23.0	7	15	3.0
Sample grade	—	—	—	—	—

Sample grade: Does not meet the stated requirements of grades 1 to 5, or contains stones or cinders, has a musty or sour odor, is heating or hot, or is of distinctly low quality.

[1] Anon. (1957)
[2] Kernels and pieces of corn passing through a No. 12 sieve.

These three basic classes are further qualified as Flint, if 95 per cent or more of the kernels (by weight) are of the flint varieties. If it meets this requirement, the grain would be classed as Yellow Flint Corn, White Flint Corn, or Mixed Flint Corn, as appropriate. "Flint and Dent Corn" is a mixture of the flint and dent varieties which includes from 5 to 95 per cent flint. Dent corn requires no modifying adjective signifying the variety.

Each named category must also be classified into one of five numerical grades or into sample grade according to the criteria listed in Table 11.

Inspection

It is clear that many of the tests required in the Standards (e.g., those for color) can only be applied by visual inspection. Their performance requires the services of qualified inspectors, and, in case of litigation based on a difference of opinion (such litigation is rather rare) the final decision must of necessity be based upon a weighing of the evidence of two or more experts. Tests of this sort are clearly less satisfactory from a theoretical standpoint than objective criteria, but they seem to function well in practice, perhaps because the producer-vendor is generally disinclined to employ an expert of his own.

When grading a lot of shelled corn, a trier or probe is used to draw a fair average sample. If it is noticed that the interior of the grain mass is appreciably warmer than the surroundings, the grain is said to be "heating" and the whole batch is graded "Sample Grade." Grain removed by the probe is examined carefully for insects. If insects (or their larvae) destructive to grain are found, the word "Weevilly" is added to the grain grade. Accidental contamination with insects of other types (e.g., ants) may be ignored. The odor of the sample is noted. If it smells musty or sour, indicating extensive microbiological activity, it is graded "Sample Grade." The same rating may be assessed if it smells noticeably of insecticides, hydrocarbons, or other foreign odorants.

Weight per bushel is determined by weighing a known volume (rarely a bushel) of grain and calculating the weight of 2,150.42 cubic inches.

A sieve with round holes $^{12}/_{64}$ inches in diameter is used to remove cracked corn and foreign material. Any material other than corn remaining on top of the sieve is removed and added to the screenings. The material removed and that passing through the screen is weighed and the percentage by weight is calculated to determine the cracked corn and foreign material.

The kernels which have been damaged mechanically or by heating are picked from a 250-gm. portion of the cleaned corn and are weighed and the percentage calculated. Heat damaged kernels are segregated from the total damaged portion and weighed separately. Heat damage is manifested by a darkening of the germ and other changes. It destroys the viability of the grain and reduces its milling quality.

Only the test required for fixing the lowest possible grade need be made. Thus, corn which is sour or musty immediately falls into Sample Grade and the tests for damaged kernels, bushel weight, foreign material, etc., need not be considered.

A water oven method of determining moisture percentage is the legally prescribed technique, but in practice, moisture may be determined in

several ways. The AOAC Methods (Anon. 1955) requires heating a sample at 266$\pm$ 5° F. and atmospheric pressure for one hour, or at 208 to 212° F. and 25 mm. pressure until constant weight is attained (about five hours).

Other "Official" tests not required by the Standards, but which are occasionally run for special purposes are ash, extract soluble in cold water, crude fiber, crude fat, fat acidity, and total protein. Details of these tests may be obtained by referring to the Official and Tentative Methods of the Association of Official Agricultural Chemists (Anon. 1955).

POPCORN

The use of corn as the expanded or puffed kernel is certainly very ancient, examples of grain suitable for this purpose having been found not only in the Toltec pyramids of Central America, but also in 4,000 year old deposits in the Bat Cave of New Mexico. Popcorn has always been predominantly an American food, although fairly large quantities are sold in England, principally as caramel-coated confections, and much lesser quantities in other countries of the Eastern hemisphere.

In the United States, popcorn growing and processing are big businesses. The 176,400 acres which were planted to this crop in 1956 yielded about a third of a billion pounds of ear corn. The leading states in popcorn production are Iowa and Illinois. In addition, Ohio, Missouri, Nebraska, and Kentucky each normally plant more than 10,000 acres annually.

Cultivation procedures for popcorn are not much different from those used for other corn crops. Time of seeding, optimum soil and climate conditions, diseases, and harvesting procedures are much the same as those for dent corn. Popcorn growers usually have more trouble with weeds because their crop grows slower than dent corn and the plants are lower in stature at maturity. The conventional 40-inch distance between hills used for dent and flint corn is also followed in planting popcorn, but the latter grain is usually seeded at a higher rate per hill, five kernels per hill being a common rate for check planted popcorn.

Popcorn is a favorite crop with home gardeners, and doubtless as much is produced by them as by commercial growers, although figures for the small plots do not show up in the yield records. Commercial producers of popcorn almost always operate under contract with a large merchandising concern which provides the seed and offers an assured outlet for the product. Because of this close control by relatively few persons, annual yield figures are subject to great fluctuations whereas field corn yields are more inflexible as a result of the greater inertia of

a larger body of independent growers. Popcorn sells for considerably more per bushel (70 lbs. of ear corn) than field corn, but the yield per acre is less and cultivation procedures are more time-consuming.

Some of the favorite varieties of popcorn are Japanese hullless, South American, White Rice, Tom Thumb, and Yellow Pearl. Hybrid popcorns are now sown more widely than the pure varieties. Purdue and Iowa State College carry on extensive breeding program for the development of superior hybrids, each organization growing more than 2,000 crosses annually. Hybrids are carefully graded for yield per acre, lodging tendencies, disease resistance, and amount of expansion of the kernels.

The fluffy white irregular mass that is a kernel of popped corn represents expanded endosperm of the original grain. The apparent volume of the kernel increases 30 times or more when it undergoes popping. The thick and horny outer layers remain attached to the puffed endosperm in an unexpanded form. Many kinds of cereal grains can be made to pop or puff under carefully controlled conditions, as will be described in the chapter on Breakfast Cereal Production, but popcorn has the peculiar quality of undergoing puffing even when the heat is applied relatively slowly at atmospheric pressure. This property makes it suitable for preparation in the home with simple equipment.

The popping of corn is unquestionably related to a sudden expansion of steam in the intercellular spaces of the endosperm. A satisfactory explanation of this phenomenon cannot be found in the literature although some speculations appear. It is not related to any obvious differences in the chemical composition of the grain. As was shown in Table 9, popcorn has slightly more protein, on the average, than the dent varieties, but the ranges for normal kernels overlap considerably so that protein quantity alone cannot be the sole factor. Considerable research work has been directed toward elucidating the difference between the starches of popcorn and other corn, but it has become evident that there is no appreciable difference between the structure. The ratio of amylose to amylopectin, the molecule size and branch length, and the granule size and shape of the starch are all very much the same in popcorn and certain varieties of non-popping corn. It may be that the very tough, thick, and continuous bran coat retains the steam until pressures in the puffing range are built up, at which time it ruptures, suddenly releasing the endosperm with its content of superheated water vapor. However, it has been reported that chunks of endosperm free of the seed coat can be popped. Details of this experiment were not given.

The optimum moisture percentage for popping has been recommended as 13.5 per cent. In working with four hybrids, Huelsen and Bemis (1954) found that increasing the moisture, at least to about 14.0 per cent,

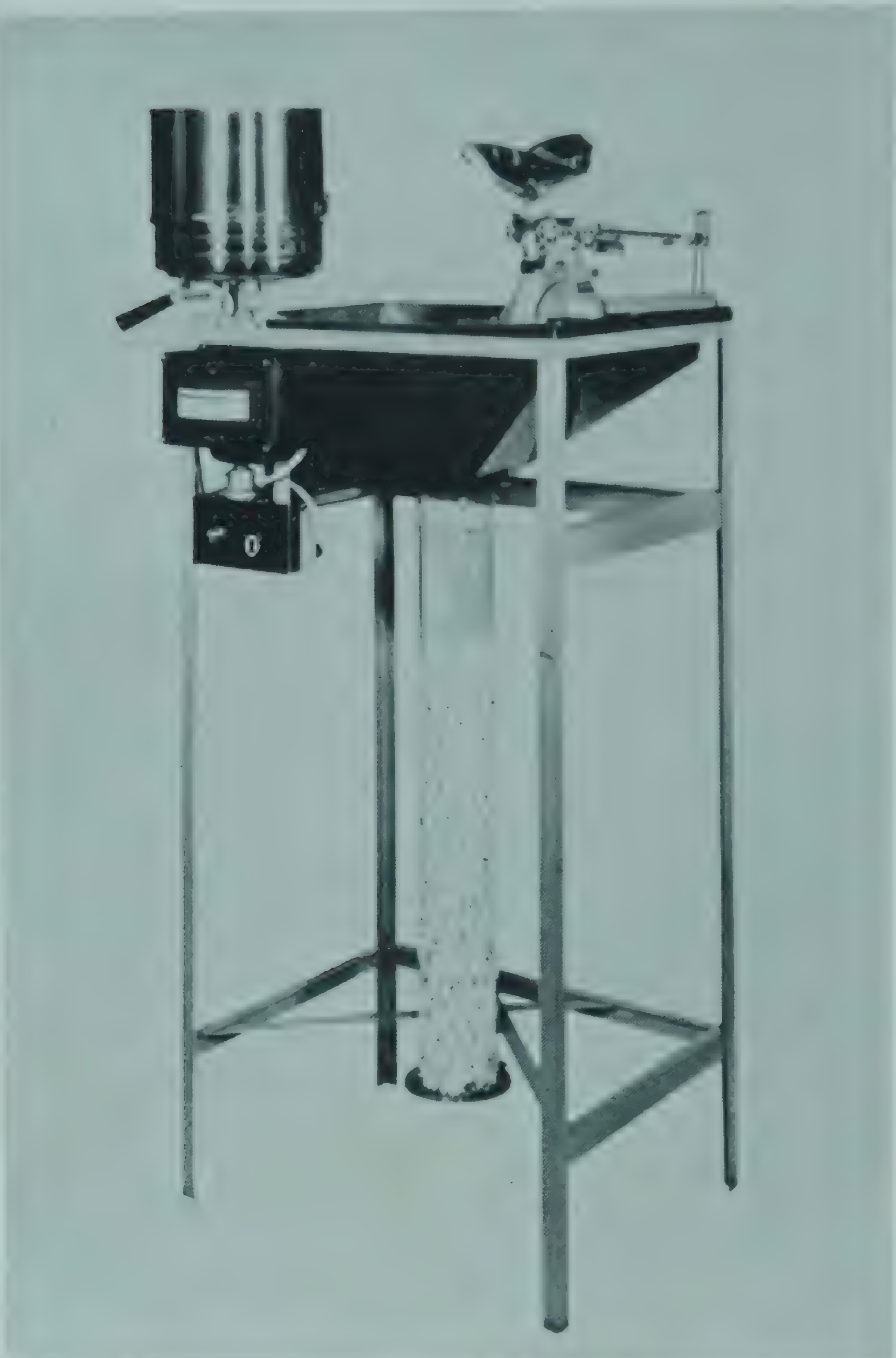
increased expansion. However, the response to increasing moisture differed with respect to maturity at harvest and popping temperatures. Corn harvested at greater maturity (e.g., 15.65 per cent moisture) gave higher popping expansion than a lot harvested at 31 per cent moisture. The temperature of the popper giving optimum expansion varied with the different hybrids. Reducing the moisture content at popping likewise reduced the required popping time. There was an inverse relationship between popping expansion and time required to pop. The temperature at which popping began decreased with increasing moisture content.

In home preparation, corn is usually popped in oil to provide better conduction of the heat, but in large-scale production, electrical heating (sometimes radiant) of "dry" kernels is frequently employed. The temperature required for popping can range from 300° to 450°F.

Although commercial distributors of popcorn claim that they consider the kernel texture, flavor, color, and other subjective characteristics in selecting seed varieties, the chief basis for judging popcorn desirability has always been the relative amount of kernel expansion that is obtained when the corn is popped. This is a natural tendency, since expansion is closely related to the price received by the processor. Popped corn is usually sold and bought by the consumer (in amusement parks, theatres, etc.) on the basis of volume rather than weight. The concessionaire must fill a box or bag of given volume with popped corn, regardless of whether he has a raw popcorn of high or low expansion. Naturally, he prefers a corn of high expansion since this means he will have to purchase fewer pounds of raw material to fill the required number of containers.

The trade measures expansion by popping a given weight or volume of corn under controlled conditions, dumping the popped kernels into a graduated plastic cylinder of standard diameter and reading the height of the column. Formerly, a standard volume of kernels was used for test popping, but measurement in this manner did not always accurately express the contribution of kernel weight to the results, so a change was made in the procedure, and, currently, a standard weight of grain is used in the test. Results are now expressed as cubic inches of popped corn obtained per pound of raw corn. In the volume versus volume test the volume of unpopped corn used filled the graduated tube to a height of one inch, and the height of the column of popped corn in inches was the expansion ratio of the corn. Most commercial corn gives an expansion between 30- and 35-fold, although a few recently developed hybrids give expansion ratios as high as 40-fold (Nelson 1955).

It has been suggested (Richardson 1957) that pericarp thickness



Courtesy of C. Cretors Co.

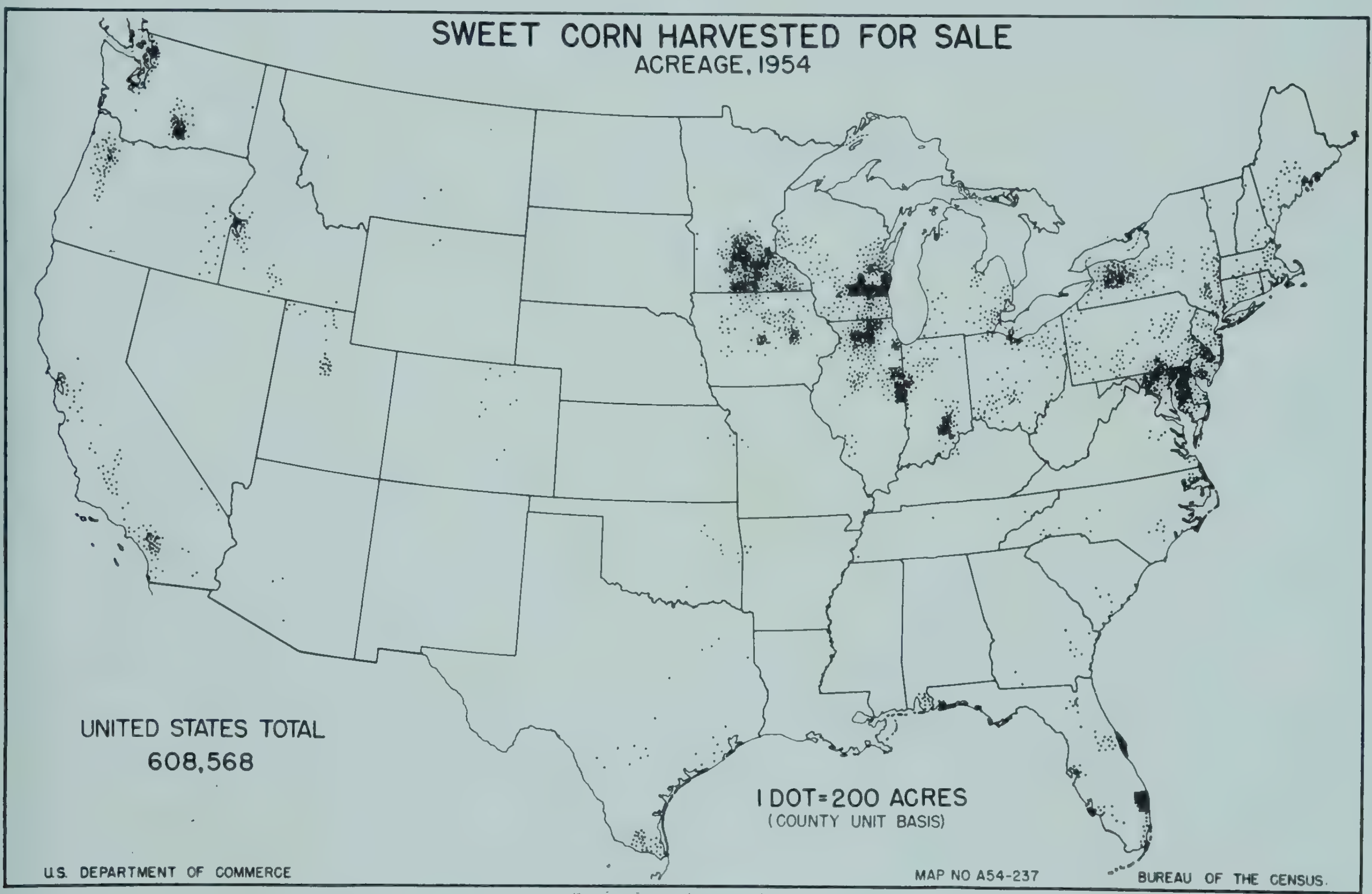
FIG. 15. OFFICIAL WEIGHT-VOLUME TESTER FOR POPCORN

should be used as another indicator of popcorn quality. In this test, the pericarp sections are mounted on edge in modeling clay and observed under a compound microscope equipped with an ocular micrometer. Hull sections are more easily obtained from popped samples than from unpopped kernels. The pericarp thickness is expressed in microns, and in a large series of hybrid corn samples varied between 41 and 65. The measurement is thought to give an indication of quality because it is related to the amount of tough, horny material remaining on the popped corn and thus is related to the acceptability of the product. Pericarp thickness is largely influenced by genetic factors although changes in the environment have some effect (Richardson 1958).

SWEET CORN

Introduction

Sweet corn differs from field corn in that a large proportion of the carbohydrates of the kernel is present as glucose polymers of fairly low molecular weight (dextrins) rather than as starch granules. As a consequence, the kernels of sweet corn retain their tender and succulent texture, and their sweet taste for a much longer period of time during their development. Sweet corn kernels when matured and dried, are as hard as those of field corn, although they have a wrinkled surface. On the other hand, certain varieties of field corn are often sold as sweet corn when in the immature stages. This is particularly true in the Southern



Courtesy of U.S. Dept. Commerce

FIG. 16. SWEET CORN HARVESTED FOR SALE IN THE UNITED STATES

United States where the greater susceptibility of sweet corn to disease and insect infestation has prohibited its economical production until very recently.

Sweet corn is regarded by some botanists as a distinct species or subspecies (*Zea mays saccharata*) extant since prehistoric times, while other authorities (Erwin 1951) consider it to be a field-corn mutation of fairly recent origin. The mutated gene is presumably the one responsible for initiating the mechanism whereby the carbohydrates of the kernel are transformed into granules containing high molecular weight branched

starches. It is said that single mutant kernels having the characteristics of sweet corn have been observed on ears of flint corn grown under controlled pollination. However, it is noteworthy that sweet corn differs from field corn in many respects. It is more susceptible to attacks by pathogens, for example. Whether these additional differences result from the operation of the same mutant gene which interferes with starch granule production or whether they are independent phenotypes remains to be proven.

Seed-bed preparation, planting, and cultivation of sweet corn are similar to the procedures used for field corn. Harvesting is usually performed by machines which cut the ears off the stalk so that bruising of the tender kernels is kept to a minimum. The time of harvesting is quite critical and is usually about 18 days after silking. Even the most tolerant varieties retain satisfactory canning quality for a period of only 6 to 8 days. In other varieties, this period of optimum quality may be as short as two days. Sweet corn yields from about $^1/_2$ to $^2/_3$ as much dry matter per acre as do the best varieties of field corn under similar conditions. Most aspects of sweet corn growing and processing have been excellently presented by Huelsen (1954).

Quality of Sweet Corn

The two principal factors contributing to sweet corn acceptability are apparently its sweetness and its tenderness. Tests to measure these factors must be rapid and accurate, since maturation proceeds very rapidly in many varieties of sweet corn and relatively small changes, percentage-wise, can cause appreciable changes in the sensory quality of the product. For example, Geise (1953) determined the smallest increment in certain quality test results which could be detected subjectively by experienced judges at a 95 per cent level of confidence. It was found that these increments were 0.52 per cent for moisture, 0.06 per cent for pericarp, 0.95 per cent for alcohol insoluble solids, and 0.68 ml. for differences in volume of 20 kernels. Most practical tests for determining the suitability of the raw material for processing are based on measurements of the hardness of the kernels, or of the moisture content. These tests range from very simple ones, as in the common thumbnail test used by experienced field men, to relatively well instrumented ones as in the succulometer test or in moisture tests by electronic devices.

The thumbnail test involves pressing the kernels while they are still on the cob and judging the "juiciness" and softness of the corn. Another visual and subjective test is based on the number of dented kernels on the ears. Ears showing kernels with concavities in the crown, indicating loss of moisture, are too far advanced in maturity to process properly into

a high quality product. According to Huelsen (1954), lots of Country Gentleman and Evergreen varieties in which more than five per cent of the ears have one or more dented kernels are not suitable for packing as fancy cream style corn. Corn at this stage contains about 68 per cent moisture.

Henry *et al.* (1956) showed that the quality of the flavor, skin texture, endosperm texture, and color decreased as the corn matured to less than 76 per cent moisture. When the moisture fell below 70 per cent, these adverse changes were accelerated. The per cent reducing sugars and total sugars traced a downward course as the corn matured.

Caldwell (1939) suggested the use of a puncture test to determine toughness of the pericarp since it is known that the pericarp becomes thinner and harder as the corn matures. However, there are differences in pericarp toughness between varieties at any given stage of maturity (Haber 1931).

Henry *et al.* (1956) surveyed a number of the methods which have been suggested for use as indicators of sweet corn maturity. Results of the various moisture tests studied—Steinlite moisture meter, succulometer, percentage of moisture by the vacuum oven method or calcium carbide method, and the per cent soluble solids by refractometer—were well correlated with the degree of maturity. Measurement of the turbidity of the juice was found to be a rather impractical test for control laboratory use although the results of the test appeared to be correlated with maturity down to about 70 per cent moisture content. The ethanol-insoluble solids content was a good indicator of the degree of maturity and the values for raw and canned samples agreed rather well.

Canned products containing field corn must be so labeled. A test to identify field corn kernels intermixed with sweet corn was developed by Heid (1928). This determination involves placing alcohol-hardened fragments of endosperm from a large number of kernels in the depressions of a spot plate and covering them with an iodine stain. A brown cloud of dextrin will disseminate from the particles of sweet corn, while the solution surrounding the field corn will remain clear. The field corn fragments will be blue-black and sharply outlined. Wildman (1932) points out that care must be used in interpreting the results of this test because kernels of immature sweet corn do not contain enough dextrin to produce the dense brown coloration characteristic of more mature sweet corn.

In the subsequent paragraphs, a brief discussion of each major processing method applied to sweet corn will be given. Although an attempt has been made to keep the first section of this volume relatively free from

processing details, considerations of space and fluency dictated the inclusion of some such material in this chapter.

Canning

Most canned corn is marketed either as cream style or as whole kernel, although a small amount of corn-on-the-cob and some combination items (e.g. corn with peppers) are canned. Cream style corn includes portions of kernels cut from the cob and the scraped residue of the portions remaining on the cob. Small amounts of corn or wheat starch, natural or modified, may be added to thicken the can contents.

Practically all canned corn is sweet corn. The amount of field corn canned (as such, excluding hominy) is negligible. The corn for canning is grown under contract with a processor. The canner provides the farmer with treated seed and designates the date of planting. On maturity, the corn is purchased at a price which may be fixed at the time of the signing of the contract or may be related by some factor to the price of field corn at the time of delivery. The contractual arrangement is necessary because the factory must have a constant flow of raw material over an extended canning period, and the farmer must have an assured outlet for this very perishable crop.

Corn is received at the cannery with the husks on the ears. The corn is fed from the trucks into chutes leading to machines which cut off the ends of the cobs and strip the freed husk from the ears. Washing by high pressure jets of water removes most of the debris and many of the silks.

Removal of silks is probably the most difficult operation in the canning process. Some of this material almost always remains with the kernels as they go to the can. The problem is somewhat alleviated by using varieties of corn which have colorless silks under the husk, so that the remnants are less detectable in the finished product.

The washed ears are trimmed and sorted for defects and maturity. The more mature corn may be used for cream style while the undermature ears are processed as whole kernel corn. The sorted corn goes to cutters which either remove most of the kernel intact, for whole kernel packs, or make a relatively shallow cut so that portions of the kernel remain on the cob to provide the "cream" for cream style packs.

Cut kernels are cleaned by screening and washing, and sometimes by fanning. These procedures remove bits of cob, husk, silks, and some loose pericarp. Soluble solids are reduced by the washing process, the percentage of loss for a given lot of corn depending somewhat on the amount of endosperm exposed by the cut.

Corn is filled into cans and a hot solution of salt and sugar is added.

In cream style packs, this "brine" may be added to the corn in batch mixers and a certain amount of cooking given the product before it is filled. The composition of the brine varies from packer to packer and with the type of corn being canned. A ratio of 1 lb. of salt to 5 lbs. of sugar has been suggested for cream style corn. Total solids content of the brine may vary from 0.5 to 1.5 lbs. per gallon. From 5 to 15 lbs. of starch per 100 gallons of brine may also be added.

The following processing times for whole kernel corn packed in 307 x 306 cans have been suggested: 35 minutes at 250°F., 45 minutes at 245°F., or 55 minutes at 240°F. Requirements for successful processing at these times and temperatures are 23 inches of closing vacuum, the presence of at least one ounce of free liquid, and a filled weight not exceeding 11.2 ounces of corn.

Dehydration

A small amount of sweet corn is dehydrated. This product is used primarily in Armed Forces' operational rations, although it has also appeared in grocery stores from time to time. During World War II, it enjoyed a minor vogue. Little is being sold to consumers at present. Both white and yellow kernels can be and have been dehydrated. Garner *et al.* (1955 and 1955A) give technical details of the drying process. Usually dehydration is performed at atmospheric pressure and at moderate temperatures, although the advantages of freeze-drying are very noticeable in dried sweet corn.

Processing techniques are relatively simple. While it is still on the cob, the corn is blanched with atmospheric pressure steam. The procedure decreases the leaching of solubles which reaches significant proportions when the kernels are hot water blanched, particularly if they are cut from the cob before blanching. The blanched kernels are cut from the cob using techniques similar to those found in the canning process and are packed from one to three inches deep in perforated metal trays. The filled trays are placed in a tunnel dryer or similar apparatus and subjected to a blast of air at a temperature of about 180°F. The temperature may be programmed to decrease as the moisture of the corn drops. Drying is discontinued when the moisture content reaches 5 to 6 per cent.

Properly dehydrated corn rehydrates into a fairly satisfactory product although usually it is not comparable with good canned corn in flavor or appearance. Penetration of water through intact pericarp is very slow, and, where speed of rehydration is important (as in Armed Forces' rations), it is desirable to have a large opening at the cob end of the kernel or to provide additional openings for the entrance of water.

Dehydrated corn stales by way of browning reactions, leading to off-colors, off-odors, and off-flavors, by bleaching of carotenoids, and by other similar deteriorative processes. Maximum stability, when fully protected by moistureproof packaging, is about 4 to 6 months at 100°F., and 12 to 18 months at 70°F.

Freezing

Large quantities of sweet corn are frozen. A small but increasing fraction appears on the market as corn-on-the-cob, but the greatest amount is sold as whole kernel corn. There is also a frozen counterpart of cream-style corn. Frozen succotash is packaged. Tressler and Evers (1957) give a very thorough discussion of methods of preparing these products. In general, manufacturing techniques down to the point of packaging are rather similar for canned and frozen corn.

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T. R. Stanton

Oats

INTRODUCTION

Oats constitute an important feed grain crop of the United States and many other countries. World production in pounds averages one-third that of wheat and two-fifths that of rice or corn. The United States and Canada produce nearly half of the world crop which usually totals slightly over four billion bushels annually. Oats are utilized primarily as feed for domestic animals. Although their bone- and muscle-building components and other desirable nutrient values are well-known, less than five per cent of the world crop is utilized as human food. A greater appreciation of oats as a food and the finding of new industrial uses for the crop are of paramount importance to its future.

IMPORTANCE OF OATS

As a World Crop

Annual world production of oats usually totals a little more than four billion bushels. The five leading oat-producing countries are the United States, Russia, Canada, Germany, and France, with an annual production in millions of bushels of approximately 1,350, 800, 460, 300, and 250, respectively. This production embraces about three-fourths of the world's total annual crop. The remaining one-fourth is produced by the many smaller oat-producing countries such as the United Kingdom, Denmark, Sweden, Czechoslovakia, and Argentina. Oats usually rank high in importance among the grains of the latter group of countries, although the importance of the crop has fluctuated greatly in recent decades because of internal disturbances in these countries incident to two World Wars.

As a Crop in the United States

Oats are the third most important cereal crop of the United States. They are grown on more than 40 million acres annually, with an average annual production of around 1,350 million bushels. Contrary to much popular thinking, oats have held their place in the agriculture of the

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Courtesy of U.S. Dept. Commerce

Fig. 17. Oats Threshed in the United States in 1954

United States not as a cash crop, but because of the great usefulness of the crop in rotations and as feed for domestic animals, and because of the relatively small amount of labor required for growing and handling the crop.

It is unfortunate that for some years low acre returns of inferior quality oats and the replacement of the horse with the tractor made oats the common "whipping boy" of the agricultural economist. A recommended reduction in the acreage of oats was an annual feature of farm outlook reports. There is no doubt that oat production declined to some extent in the 1930's owing to low yield and low quality resulting primarily from rusts. Hence, there really was some justification for the belief that the crop was deteriorating. Nevertheless, during the last decade and a half the economic status of oats has been greatly improved by breeding and distribution of superior new disease-resistant and more productive varieties. A more consistently higher yield of better quality oats made a "come-back" possible for the crop. Fig. 17 illustrates the distribution of oats produced for grain during a recent year.

ORIGIN OF THE OAT PLANT

The origin of oats, as is true of most economic plants, is shrouded in obscurity and mystery. Mal'tzev (1830), a modern Russian systematist,

is of the opinion that there is no definite record to lead botanists to believe that oats were known to the ancient Chinese, Hebrews, or Hindus. The writers of classical antiquity, such as Cato, Cicero, Theophrastus, Ovid, and Varro, apparently refer to oats only as a weed which was used for medicinal purposes.

The Common Oat, by far the one most important of all the cultivated and botanical forms of *Avena,* apparently was first found growing in different regions of Europe, from where it spread to various parts of the world, especially into regions having a suitable environment for its satisfactory growth. There is a possibility, however, that it may have been first grown by the ancient slavonic people who inhabited Western Europe during the Iron and Bronze Ages. Mal'tzev also believes that the group of oats belonging to the cycle *Avena fatua* (Wild Oat), the most generally accepted progenitor of *A. sativa* (Common Oat), is of Asiatic origin.

The first authentic historical records on cultivated oats appear at the beginning of the Christian era. The writings of Columbella, Dioscorides, Pliny, and other historical writers of the early Christian era indicate that the Common Oat (*A. sativa*) was grown by Europeans for grain and the Red Oat (*A. byzantina*) for forage purposes, especially in Asia Minor. As a consequence, the most authentic information available leads to the belief that the cultivated Red Oat of the southern United States, South America, Australia, and the Mediterranean region of Europe with similar warm climates, had a common origin, that is, in Asia Minor, west of the Mediterranean. Again since the Red Oat appears not to have been found anywhere in ancient excavations, it is considered to be of more recent origin than the Common Oat. Evidence published rather recently, however, indicates that this may be in error and the theory is advanced that the Common Oat originated from the Red Oat and that the latter is thus the older species (Coffman 1946).

Among the early writers of the Christian era the belief obtained to some extent that oats were probably first found as a weed which infested fields of barley. Hence, oats may have been first widely distributed as a mixture in barley and later selected and domesticated as a separate crop. The fact that Harlan found oats of the minor species *Avena abyssinica* growing wild only as a weed in barley in Ethiopia lends support to this theory (Stanton and Dorsey 1927).

THE HISTORY OF OATS IN AMERICA

It appears that oats were first brought to America, along with other small grains, by Captain Gosnold, who grew these grains on one of the Elizabeth Islands off the southern coast of Massachusetts in 1602. In

Virginia the first oats probably were sown as early as 1611 at the time wheat was first tried by the Jamestown colony. Nevertheless, owing to unsuitable varieties, primitive cultural methods, a somewhat unfavorable climate, and a lack of definite information on the growing of these crops in a new environment, it appears that neither wheat nor oats was immediately satisfactorily grown by these early colonists.

Ultimately, the growing of oats became well established on the Atlantic Seaboard of the United States and then spread westward across the Appalachian Mountains into the rich soil region of the Ohio Valley. A further great shift westward followed the close of the Revolutionary war into the great central or Mississippi Valley region of the United States now known as the Corn Belt. This vast region could equally well be referred to as the "Oat Belt" because it is here that the great bulk of the oat crop is grown today. This westward shift continued until the middle of the eighteenth century.

The great expansion of oat production westward naturally went hand in hand with the very rapid development of agriculture in general that took place from about 1870 to almost the end of the nineteenth century. Several less marked periods of expansion westward followed until, in the decade ending with 1950, production reached its peak and the crop approached or exceeded one and one-half billion bushels in four of the ten years of this decade.

For further details on the development and westward advance of oat production in the United States, see Ball *et al.* (1922) and Stanton (1953).

INTERNAL AND EXPORT TRADE

Oats are of relatively limited importance in the grain markets because a high percentage of the crop is fed on the home farm and less than five per cent of the world crop is processed into food for human consumption. Thus the bulk of the crop is consumed by farm animals, especially hogs, dairy cows, poultry, and young breeding stock of all kinds. Formerly, horses consumed more oats than all other farm animals combined. As feed for these animals, oats are almost unsurpassed since the oat grain is high in protein, fat, vitamin B_1, and minerals such as phosphorus and iron.

The United States is exporting slightly more oats in recent years than it did formerly. During the five year period from 1951 through 1955, an average of about twelve million bushels has been exported to European and other countries annually. Thus exports (including meal) have been very low and relatively insignificant, ranging in the period 1945 to 1955 from as low as three million bushels in 1953 to a high of approximately 30 million bushels in 1955. However, during these years considerable

amounts of oats have been imported into the United States from Canada. For the four year period 1950 through 1953, an annual average of about 55 million bushels were received. Owing to the excellent quality of Canadian oats they are highly valued by commercial dealers, race horse enthusiasts, and producers of certain classes of live stock. Not many Canadian oats are milled in the United States owing to a somewhat higher cost differential.

NATURAL FACTORS AFFECTING OAT PRODUCTION

Rainfall and Temperature

The oat plant grows best in cool, moist regions such as the northern United States, southern Canada, and northern Europe. The important natural factors affecting the growth and development of the plant in any region includes rainfall, temperature, winterkilling (in winter oats), soil productivity, diseases, and insects. The leading oat producing areas are found in the more humid parts of the world as the oat plant requires more water for its best development than any other small grain.

Hot dry weather when the grain is beginning to mature frequently causes premature ripening and reduction in yield and quality, whereas hot, humid weather during this period, or slightly earlier, favors the infection with, and development of, disease organisms, especially rusts which markedly reduce the yield and quality.

Winterkilling in Fall-Sown Oats

Winterkilling sometimes results in serious reduction in stand and yield when oats are sown in the fall. In recent years, the distribution of new hardier or more cold-resistant varieties of fall-sown oats, such as Forkedeer, Wintok, and Dubois, has decidedly reduced losses from freezing. This crop thus provides a soil cover and much valuable grazing during the winter, and, if needed, an excellent hay crop the next May. Fall-sown oats mature earlier than do spring-sown oats and consequently escape to some degree infection by rusts and the effects of other diseases. Hence, winter- or fall-sown oats, where adapted, produce higher acre yields of better quality grain than do spring oats. Another advantage is the earlier removal of the crop from the land, which enables earlier and more timely planting of the succeeding crop. As a rule, a better distribution of farm labor also results from sowing the oats in the fall.

Soil Productivity

Oats grow best on rich soils, and no other crop responds so well to good fertilizer treatment when grown on fair to medium soils. The crop therefore can be grown very satisfactorily on rather poor sandy soils such

as are found in the southeastern and southern United States. Here, when grown in a proper rotation, on soils well supplied with organic matter and the proper mineral fertilizers at time of seeding, high acre yields are obtained. The yields of winter oats usually are greatly augmented by applying nitrogen in the late winter or early spring as a top dressing.

It thus may be said that oats are less demanding in natural soil fertility and are better adapted as a poor-land crop than any of the small grains, except rye.

Diseases

The most serious diseases attacking oats are the rusts, smuts, Victoria blight, and foot rots. Other oat diseases, usually less destructive, include *Helminthosporium* blight, Septoria black stem, mildew, viruses (mosaics), and anthracnose.

In England, the so-called gray-speck disease is common on oats. It is caused primarily by a deficiency of manganese in the soil. Very little gray-speck has been seen in the United States. At any rate, this trouble can be relatively easily corrected by application of manganese to the soil.

Rusts have been especially destructive in the United States, but in recent years losses have been markedly reduced by the development and distribution of improved disease-resistant varieties. The oat smuts likewise have been common, but they are easier to control by seed treatment. They also are controlled by growing resistant varieties.

The wider and more intensive use of new and efficient fungicides, such as New Improved Ceresan or Pantogen, for seed treatment, together with the growing of resistant varieties, has resulted in reducing losses from the oat smuts to a minimum.

From 1945 to 1947 very heavy losses of oats were caused by Victoria blight (*Helminthosporium victoriae* (Meehan and Murphy)), then a new and very destructive disease. This disease, however, was fairly quickly controlled by the development and distribution of varieties with resistant germ plasm derived from Bond oat crosses, and by the end of the 1951 harvest, it had almost disappeared in many sections.

Helminthosporium avenae, Phythium debaryanum and other foot-rot organisms have caused losses in some sections in certain years. However, these are usually considered in the category of minor diseases and have not seriously affected oat production. Mildew also falls in this category and infrequently causes some losses to winter oats in the south.

Insect Pests

The growing oat crop is relatively free from attacks of insects pests, except for the occasional attacks of the green bug or plant aphid in the

central and south central states, especially in Oklahoma and Texas. Infestations of this predator have been more abundant in recent decades. However, populations seem to have declined during the last few years and consequent losses to the crop have been correspondingly reduced. Attempts are being made to discover or breed varieties resistant to green bug injury with only fair success. So far no green bug resistant varieties have been distributed commercially.

The frit fly in England has been controlled by the distribution of resistant varieties.

Predators such as chinch bugs and various stem borers, which have been so destructive to many other grain crops, have caused little damage to oats.

BOTANY OF THE OAT PLANT

The Genus *Avena*

The genus *Avena* apparently was established in 1700 by Tournefort, a French explorer and botanist. Most species of oats known today were first described as early as 1750 by Linnaeus, the great Swedish botanist.

As already indicated, the Common Oat (*Avena sativa*) is grown in the cooler and moister temperate regions of the world, and embraces most of the oats produced today. The Red Oat (*A. byzantina*) is grown in regions considered too warm for satisfactory growth of the Common Oat. If it were not for these heat-tolerant Red Oats, oat production would be much less important in the southern United States, South America, Australia, and the Mediterranean countries of Europe.

Stanton (1955) published a description of the oat plant which is quoted as follows:

"The oat plant is an annual grass belonging to the genus *Avena*. Cultivated oats are derived chiefly from two species, the common wild oat (*A. fatua* L.) and the wild red (*A. sterilis* L.). The principal derivatives of the former are the common oat (*A. sativa* L.), including the side oat (*A. orientalis Schreb.*). Of the latter, the only important cultivated form is *A. byzantina* (C. Koch), including *A. sterilis algeriensis* Trabut."

"Under average conditions the oat plant produces from three to five hollow stems, or culms, varying from one-eighth to one-fourth inch in diameter and from two to five feet in height. The roots are small, numerous and fibrous, and penetrate the soil to a depth of several feet. The leaves average about ten inches in length and five-eighths of an inch in width. The panicles, or heads, are either spreading (equilateral, or tree-like) or one-sided (unilateral, horse-mane, or banner-like). By far the greater number of cultivated varieties have spreading panicles. The

Courtesy of U.S. Dept. Agr.

FIG. 18. THE INFLORESCENCE OF COMMON OATS

(1) Panicle of *Avena sativa;* (2) distal or top part of panicle, bearing four spikelets; (3) lateral view of spikelet (one-flowered) in anthesis, showing separated lemma and palea with one branch of plumose stigma and three stamens (7) protruding; (4) lateral view of lemma, showing dorsal

grain is produced on small branches, in spikelets, varying in number from 20 to 150 per panicle. Each spikelet contains two or three florets or grains except those of the hull-less or naked oat which contain four to eight. The spikelet is loosely enclosed within the outer glumes (chaff). The kernels, except in the hull-less oat, are tightly enclosed in the lemmas or inner glumes and palea. The lemma or hull ranges in color from white, yellow, gray, and red, to black, and may be awned or awnless. The kernel, or more properly the caryopsis, without its adhering glumes, is very slender, ranging from five- to seven-sixteenths of an inch in length and from one- to two-sixteenths of an inch in width. The kernel constitutes 65 to 75 per cent of the total weight of the whole grain." Some of these structures are shown in Fig. 18.

For additional information on the oat species and varieties, including description, history, and distribution of the species and varieties, see Stanton (1955).

Many Varieties

Several hundred varieties of oats may be differentiated on the basis of botanical characters. Through the years the total number of named commercial varieties that appeared from time to time ran into the thousands. The so-called World Collection of Oats on file in the Field Crops Research Branch, Agricultural Research Service, United States Department of Agriculture, Beltsville, Maryland, contains nearly 5,000 varieties and strains. Most of these are simply named or unnamed strains of a much smaller number of definite botanical varieties and types, that is, there are many duplicates. During the last two decades the adoption by farmers of

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attachment of awn; (5) ventral view of palea; (6) lodicules; (7) stamens; (8 to 13) lateral views of a floret before, during, and after anthesis; (14) diagrammatic longitudinal dorsal-ventral section of floret; showing lemma, palea, androecium, and gynoecium; (15) diagrammatic cross section of spiketlets of three-flowered spikelet before anthesis—(a) lower, or outer, glume, (b) upper, or inner, glume, (c) lemma, or flowering glume, (d) palea, (e) anthers, (f) stigma, (g) lemma of secondary floret with enclosed palea, stamens, and stigma, (h) rudimentary tertiary floret; (16 to 18) androecium before, during, and after anthesis; (19) apical portion of stigma, greatly enlarged, showing adhering pollen grains; (20) diagrammatic cross section of anther; (21) pollen grains, enormously enlarged; (22) floret, ventral and dorsal view of caryopses; (23) mature primary floret (kernel), ventral view, showing inrolled edges of lemma, dorsal view of central part of palea, and attached rachilla segment which bore the secondary floret; (24) caryopsis, dorsal view, showing embryo, scutellum, and pubescence on seedcoat; (25) caryopsis, ventral view; (26) caryopsis, lateral longitudinal (sagittal) view, showing endosperm and embryo; (27) caryopsis, cross section. (Original drawing by Boettcher, redrawn by Mrs. Regina O. Hughes.)

improved or selected varieties recommended by State Agricultural Experiment Stations and Extension Services has, fortunately, reduced the number of named, often nondescript, disease-susceptible, low-yielding varieties that plagued the farmer for years.

Classification of Species and Varieties

Stanton (1953), in his rather comprehensive studies on the identification and classification of oats, described 12 species or subspecies of *Avena* including: (1) Large Naked Oat (*Avena nuda* L.), (2) Small Naked Oat (*A. nudibrevis* var., *A. nuda* L. ssp. *biaristata* (Alef.) Asch. & Graeb.), (3) Wild Red Oat (*A. sterilis* L.), (4) Red Oat (*A. byzantina* C. Koch), (5) Desert Oat (*A. wiestii Steud.*), (6) Slender Oat (*A. barbata* Brot.), (7) Sand Oat (*A. strigosa* Schreb.), Abyssinian Oat (*A. abyssinica* Hochst.), (9) Short Oat (*A. brevis* Roth.), (10) Wild Oat (*A. fatua* L.), (11) (Common) Tree Oat (*A. sativa* L. ssp. *diffusa* (Neils.) Asch. and Graeb.), and (12) (Common) Side Oat (*A. sativa* L. ssp. *orientalis* Schreb.).

Unfortunately, space permits only brief discussion of the varieties of Red, (Common) Tree, and (Common) Side Oats in this book. Brief reference to the large Naked or Hull-less Oat also is made due to the fact that a few hull-less oats are grown commercially on farms in the United States.

Stanton (1953) described only four varieties of the Large Naked Oat and named six synonymous varieties. Because of low yield and other agronomic disadvantages, the Naked Oat never attained much economic importance in the United States. However, a few are grown each year more as a novelty than as a standard crop by farmers who become curious.

Stanton described 50 varieties of the Red Oat. Of these, 28 have been grouped in the key as representing true *sterilis* types with second floret separating quite consistently by basifracture, and 22 as intermediate types with second florets not separating consistently by basifracture, heterofracture (intermediate), or disarticulation, best exemplified by the Burt and Fulghum varieties. In addition, 60 synonymous varieties were named.

Stanton described 146 varieties of the (Common)Tree Oat and named 165 synonymous varieties. He also described 18 varieties of the (Common) Side Oat and named 16 synonymous varieties. As a group, most of the varieties with side panicles are of little economic importance, because of their low yielding power and inferior grain quality. They also have low tillering capacities and large, thick hulled grains. One Side Oat variety, viz. White Tartar (White Russian), is of value for breeding because of high resistance to certain races of stem rust.

Several other botanists have classified the varieties of oats; viz. Etheridge and Marquand. Etheridge (1916), in his classification studies including 731 collections, established 55 botanical varieties including both the Red Oat and the Common Oat. The remaining strains were either classified as synonymous varieties, or were discarded as representing badly mixed nondescript oats of no value for classification.

Marquand (1922), an English botanist, in a classification of the species and varieties of oats mostly grown in the British isles, recognized 112 varieties and sub-varieties of Red and Common oats. He also named a few synonymous varieties.

During recent years the breeding and distribution of many new disease-resistant varieties originating as selections mostly from crosses between Red and Common oats has further complicated the problem of varietal identification and classification owing to similarity in many morphological characters and disease reactions.

Genetics of Oats

Briefly, the basic genetic principles determining the mode of inheritance of morphological characters and disease reactions in oats are the same as for wheat and barley. Most characters are inherited on a monogenic basis, including the 3:1 and 1:2:1 segregations. A relatively smaller number of characters are inherited on a digenic or trigenic basis, including the 15:1 and 13:3 and 63:1 segregations. There remain many characters, mostly of a quantitative nature, that depend upon so-called multiple factors for their inheritance.

For a catalog of the various characters in oats that are transmitted by these different types of inheritance see Stanton (1937).

OAT IMPROVEMENT

Three methods of varietal improvement have been practiced in the United States and other oat-producing countries; namely, the methods of introduction, selection, and hybridization.

Introduction

The first method was practiced extensively by immigrants who brought to the New World seed of the varieties commonly grown in their homelands. During the last century, especially during the last half of the 19th century, Federal Governmental officials or explorers traveled the world, collected and introduced hundreds of new varieties into the United States for testing and distribution to farmers. Many of these became famous and were widely grown in their day.

Selection

Improvement by selection started in a big way shortly after the turn of the century. It consisted of making and testing hundreds of panicles (heads) or plant selections from the old domestic and the more recently introduced varieties. The few lines that continued to be most promising in yield and quality usually were multiplied, named, and distributed to farmers as improved varieties. A few of the older varieties that are still grown (usually on somewhat limited acreages) originated in this manner. Victory, a variety rather widely grown in all of the more northern oat countries of the world is one of the most classical examples of improvement by selection that may be cited. It originated as a pure-line selection made in Sweden from the old unselected Probsteier or Milton oat of the Baltic region of Europe. Other good examples are the Richland, Markton, Rainbow, and Nortex (Red Rustproof), all American varieties. Richland was selected in Iowa from Sixty-Day, a variety introduced from Russia in 1901. Because of the excellent resistance to stem rust, Richland became one of the most important varieties originating by selection ever grown in the United States, especially in the great central oat belt. Markton, a well-known smut-resistant oat grown in the Pacific Northwest region, was selected in Oregon from an unnamed, mixed plant population known only as Cereal Accession No. 357 which had been introduced from Turkey. Rainbow, an important stem rust resistant variety originated in North Dakota, as a pureline from the old variety Green Russian. Nortex, one of the best-known of the Rustproof type varieties may be cited as an example of improvement by selection in southern red oats.

Hybridization

The breeding of new varieties of oats by hybridization in the United States began in Vermont about 1870 but the method did not really come into vogue extensively until around 1920. Increased knowledge of plant genetics and plant pathology became available shortly after the beginning of the present century and greatly stimulated the cross-breeding of oats. This method provided a means of transferring rust, smut, and other disease resistance genes from highly disease-resistant oats to superior, high yielding, desirable agronomic types.

Backcrossing is a modification of the straight cross-breeding method. Thus, to transfer a desirable character, such as resistance to a particular race of rust, to a certain botanical variety of oats, selected progenies from the original cross that carried the desired resistance are back-crossed to the original parent. Selection and back-crossing to the recurrent parent is repeated through several hybrid generations until the desired agronomic type is recovered with satisfactory disease resistance.

There are many accessory procedures in oat breeding by hybridization, especially in breeding for disease resistance. These constitute the development of artificial epidemics to infect and eliminate susceptible progenies, and the growing, collection, identification, and application of the necessary inoculum.

Stanton (1937) summarized the results of breeding new varieties of oats in the United States, Canada, and nearly all other oat producing countries in which some important breeding work had been in progress and of which results had been made available. Many valuable varieties were recorded as originating by selection while a relatively smaller number had originated by hybridization. This treatise stimulated much more interest in the cross-breeding of oats in the years following 1937.

PRODUCTION METHODS IN THE UNITED STATES

Growing the Crop

No other small grain crop responds so well to good cultural methods as do oats. In the Corn Belt area of the United States, oats most frequently follow corn to return the land to grass or clover the third year. Thus the seed bed usually can be prepared simply by disking before seeding. In the absence of heavy crop residues plowing is seldom necessary. Furthermore, plowing may result in a rather loose, cloddy, and undesirable seedbed, especially if the spring should be wet and backward.

Seeding as early as the land can be prepared in the spring usually is good farm practice under nearly all conditions. Deferred sowing after the optimum date may decrease yield as much as three bushels per day for each day of delay. Winter or fall sown oats should be sown 3 to 4 weeks before the average date of the first killing frost for the section. Seed treatment with fungicides for control of oat smuts and other seed borne diseases is a common practice among good farmers, regardless of whether or not smut resistant varieties are being sown.

Common rates of seeding oats vary from 8 to 10 pecks per acre. The bulk of the crop is sown at these rates. Under dryland farming, however, the rate as a rule is reduced to six pecks, and under irrigation it is usually increased to twelve pecks. Where oats are sown especially for pasture or hay, the rate may be further increased to 14 or even 16 pecks to the acre.

In planting the seed, drilling is usually preferable, although the end-gate seeder for broadcasting the seed is still extensively used as less work is required and, as a rule, earlier and more timely seeding is possible. Nevertheless, drilling is a more accurate method of planting and it requires less seed, insures a more uniform distribution, and contributes to a more

complete coverage of the seed. Drilling also places the seed at uniform depth in the soil, a very essential requirement for uniform germination and the assurance of even stands.

Usually it is more profitable to apply mineral fertilizers or other soil amendments to other crops in the rotation than to oats, except on the poorer soils. Under certain conditions, however, mineral fertilizers may be applied directly to the crop with excellent results. In some sections a greater acre return per unit of fertilizers usually can be obtained from oats than from wheat or corn. Farm manure is seldom applied directly to the crop because of the danger of excessive straw growth and consequent heavy losses from lodging. Where soil amendments are needed, complete fertilizers of the formulas 5-10-5, 6-12-6, or similar combinations, are applied at the time of seeding.

In some sections good results have been obtained from formulas such as 10-10-10 or 12-12-12 which in former years were believed to contain too much nitrogen and potassium in proportion to phosphorus. In any region where soil-building legumes are included in the rotation and supplement the nitrogen content of the soil, application of 250 to 300 lbs. of superphosphate at the time of seeding is an excellent treatment for oats. In cold, wet springs, light applications of nitrate of soda, ammonium nitrate, or other concentrated nitrogen fertilizers will be beneficial to the crop until the soil warms up sufficiently to bring about soil nitrification. Much of the so-called "red leaf" trouble of malnutrition manifestations in oats in the spring is due to a lack of readily available nitrogen at a critical period in the growth of the oat plant. Consequently, nitrogen alone on the better soils or a complete fertilizer on the somewhat less fertile soils applied at the time of seeding should become a more general practice in the growing of oats.

In the case of winter oats, spring top dressing with nitrogenous fertilizers is common practice. As a rule these applications are made in late February or early March at rates of 100 to 200 lbs to the acre, except for ammonium nitrate. Because of its higher percentage of nitrogen, the latter compound is used at a lower rate.

Harvesting

In the United States the oat harvest extends over a period of nearly four months, that is, proceeding from South to North. Harvesting begins in the South with winter oats in early May. The bulk of the spring-sown crop is usually harvested in July and early August, depending on the latitude. Following delayed seeding, however, resulting from cold wet spring weather, harvesting may be as late as September 1, or even later in the more extreme northern oat areas.

Methods of harvesting oats are the same as for other small grains. The machines for harvesting have been greatly improved in both capacity and efficiency in recent decades. Within a period of 75 to 100 years the method of harvesting oats or other small grains has advanced from the old-fashioned cradle to the modern 14-foot self-propelled combine which harvests and threshes at one operation. Thus, in the span of a life-time the rate of harvesting oats has been increased from 1 acre or 2 per day per man to 30 or more acres per day.

The greatest perfection in harvesting methods is attained with the modern self-propelled combine or harvester which cuts and thrashes the grain and delivers the bulk grain to a tank truck for hauling to the granary or elevator. The fact must not be overlooked that the binder is still preferred in some areas where small acreages of oats are grown. Also, it is still used in other sections because the straw is saved for roughage and litter, and some farmers do not want to take chances of letting the oats stand in the field to become sufficiently dry for combining. Binders are also still preferred on many irrigated farms, due to the small fields and to the obstructions offered to the convenient operation of the combine by irrigation ditches and levees.

FARM STORAGE

Since more than 85 per cent of the oats produced in the United States are consumed by livestock on the farms or elsewhere in the counties where they are produced, safe storage of oats on the farm is very important. In cash-oat producing areas, such as are found in northwestern Iowa and southeastern South Dakota, a high percentage of the commercial oats are hauled to local elevators or warehouses immediately after harvesting.

In storing oats, in either farm granaries or in elevators, it is exceedingly important to have the grain dry enough for safe storage. This means that it should not contain more than 14 per cent moisture when run into the bin or elevator. If the oats contain excessive moisture when stored they may become musty or heat-damaged due to the action of molds. This markedly reduces their feed value and may render them unfit for use in foods, and, as a result their market value is less. Oats stored with 14 per cent moisture, or less, and having full protection from dampness from without, will remain sweet and in good condition for several years if subjected to proper natural aeration (Collier 1949).

The grain storage bin or granary should be well built and strong enough to resist the pressure of the grain and should also be rodent proof. Oats have the advantage that owing to their lighter bushel weight the danger of springing leaks from pressures within the granaries or elevators is much

less than in the case of wheat. As a rule, modern farm granaries and elevators are equipped with elevating machinery, thus saving hand labor and they are so built that the oats can be removed conveniently and economically.

UTILIZATION OF OATS

As previously stated, the great bulk of the oat crop the world over is utilized as feed. In the United States oats constitute an important concentrate in rations for horses, cattle, sheep, hogs, and poultry. The proportion fed to animals is probably even higher in other countries, since in no other country are rolled oats (oatmeal) consumed to the extent they are in the United States, except possibly in the United Kingdom, where Scotland is undoubtedly the heaviest consumer of the celebrated Scotch porridge made from oatmeal. Incidentally, it should be mentioned here that oatmeal or rolled oats is one of the cheapest, yet one of the most wholesome, palatable, and well-balanced foods available for children and adults (Stanton 1948). Unfortunately, oats have only limited industrial uses. Oat hulls are used in considerable quantity for the production of furfural, a chemical which has numerous industrial applications.

YIELD AND QUALITY

These factors are closely related since high yield and quality have been major objectives of oat and plant improvement in general since the time man first started to save only the best for seed by mass selection centuries ago. Undoubtedly these objectives will continue to be of the same importance in the future, as also is true of breeding for disease resistance which is related directly to quality. It could not be expected that diseased plants would produce other than poorly filled grain, or even disease infected groats.

In recent years the value of oats for both feeding and milling purposes has been lowered by a marked increase in kernel infection, especially of *Septoria avenae* in Wisconsin and other more northern corn belt states. This disease results in the presence of an occasional infected, black or dark-colored groat, or part of a groat, that gives the cooked or table-prepared rolled oats an unattractive appearance. Their conspicuousness is very annoying to the homemaker. However, it is believed that the occasional black groat has no deleterious effect on the health of the consumer. It is impossible for the mills to remove all of these undesirable groats, hence a few remain in the finished product regardless of the great efforts made by the processors to avoid this contamination.

As in other small grains, test weight or weight per bushel, is the one

most important index for the evaluation of grain quality in oats. In most states a test weight of 32 lbs. to the bushel (Winchester) is standard. The percentage of groat to hull also is an important index of quality and the one that determines much of their feeding and milling value. As a rule, high yield and high quality go hand in hand, hence where there is sufficiently healthy plant, or straw growth, the development of well-filled, plump, heavy oats usually results.

As a rule, depending somewhat on the season, the percentage of hull in oats runs from 25 to 35 per cent. Quality also depends somewhat on the variety grown. Some varieties are inherently higher producers of grain than others, regardless of soil and weather. Most of the varieties developed from crosses on Bond oats have ranked high in bushel weight because of their short, plump, thin-hulled groats. Such varieties yield a high extraction of groats and therefore a high percentage of rolled oats.

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Allan D. Dickson

Barley

INTRODUCTION

Origin of the Barley Plant

Barley, one of the world's oldest domesticated grain crops, has been widely used since biblical times. The ancient records of barley cultivation, reviewed by Weaver (1950), show that cultivated varieties were used by neolithic cultures in Egypt between 5000 and 6000 B.C. Analysis of well-preserved grain from straw-lined pits discovered in explorations showed that the barley was very similar to that presently cultivated in Egypt but distinguishable from that grown in Tunis, Syria, Persia, and India. Since no great improvement in the plant has taken place during 7,000 years, it is suggested that a very long time must have been required for barley to develop from the wild state to that of the specimens found. All available records of ancient agriculture in Asia and Europe establish the importance of barley for human food, probably eaten as a porridge and bread, and its use also in the preparation of a fermented beer. It is of interest, in relation to origin, that the earliest described barleys were all six-rowed types. The oldest authentic records of two-rowed barleys are among the Greek and Roman archives of about 300 B.C., according to Takahashi (1955). Two-rowed barley was rare until the 16th and 17th centuries, when it became rather common in Europe.

Two species of wild barley in the section Cerealia Ands. of the genus *Hordeum* are the most likely forerunners of cultivated barleys. *Hordeum spontaneum* C. Koch, a two-rowed barley with brittle rachis, was first described in 1848 and is found wild in areas of Southwestern Asia and Northern Africa. A six-rowed wild barley, *Hordeum agriocrithon* Åberg, was first found by Åberg in 1938 and has since been found in regions along the Himalaya mountain ranges. However, this may possibly be a primitive cultivated form, as samples have been found only in mixture with seed samples. Cultivated barley may have originated from either of the wild forms mentioned as they both have 14 diploid chromosomes and cross readily with cultivated forms, indicating complete compatibility. Several hypotheses for the phylogenetic development of cultivated forms

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from the above wild form have been presented by Åberg (1940 and 1948), but actual facts are still lacking.

Brucher and Åberg (1950) suggest two major gene centers of barley where cultivated varieties may have developed. One is in Abyssinia, where many different kinds grow naturally, and the other is in the highlands of Sikkim and southern Tibet.

Importance in the Economy of the United States

Adaptability.—Barley is certainly the most widely adapted cereal crop and is possibly more widely adapted than any other cultivated crop. Its cultivation in Europe extends beyond the Arctic Circle, where it reaches 70° N. latitude in Norway. To the south, barley culture extends within a few degrees of the Equator in the high mountain regions of Ethiopia, according to Nuttonson (1957). In the United States, barley is best adapted to the Northern and Western states. Over the long period of its cultivation, geographical environment and efforts of man have resulted in many diverse types. There are spring types that mature in 60 to 70 days and winter types that may require as long as 180 days. In general, barley is able to mature in a shorter season than any other major grain crop. Barley is not extremely winter hardy, nor is it favored by hot humid weather. It is the most salt tolerant of all cereals according to Spector (1956), and therefore best adapted to alkali soils. However, it is best adapted to and yields highest on fertile soils. Profitable barley production over long periods of time has been confined to areas with average summer temperatures of 70°F. or less, annual precipitation not in excess of 35 inches, and average relative humidity of less than 50 per cent, according to Weaver (1950).

Economic Importance.—Barley is the major grain crop for food and feed in northern areas or at high elevations where its short growing season makes it more dependable than wheat or oats. In the United States, it ranks fourth in importance, being exceeded by corn, wheat, and oats. In northern areas where corn is not well adapted, it is the major feed grain.

Barley is by far the most important cereal grain for malting because of specific physical and chemical properties. Approximately one-third of the annual production, or 100 million bushels, is used for this purpose annually in the United States. Before World War II, relatively large quantities of California barley were exported for malting, but this market is of minor importance at present. More recently, moderate quantities of western-grown barley have been exported to Asiatic countries for use as human food.

BOTANY OF THE BARLEY PLANT

Description of Plant and Seed

Barley is one of the cereal members of the grass family. Winter and spring types exist. The plant consists of roots, leaves, stems and flower parts. The grain is produced in spikes, or heads, at the top of the stems. Mature barley plants vary in height from 12 to 48 inches, the height depending upon type or variety and growing conditions, but 30 inches has been given as a usual height by Shands and Dickson (1953). The flowers of the plant are arranged in spikelets on the head and are attached at nodes of a flat zigzag rachis, or central stem. Three spikelets, each with a pair of glumes, are attached at each node of the rachis and successive spikelets are located on alternate sides of the rachis. The spikelet is composed of the male and female flower parts and the rachilla, enclosed within the hulls, which consist of the lemma and the palea. The lemma terminates in the awn, or beard, in awned varieties, but hooded barleys have short three-pronged appendages instead of awns. The florets open only for a short period at pollination; so barley is naturally self-pollinated.

The mature kernel is composed of hulls (lemma and palea) enclosing the caryopsis and rachilla. In most varieties, the hulls are cemented to the caryopsis and make up a part of the threshed kernel. In naked and hulless barleys, the kernel threshes free as does wheat. In six-rowed barleys, the three spikelets at each node are fertile and produce kernels, while in two-rowed forms only the central spikelet is fertile and develops a grain. Size, shape, and color of the kernels vary widely depending upon type and variety.

Classification of Cultivated Species

Plants of the genus *Hordeum* of the grass family, *Gramineae*, have simple spikes. The cultivated types of barley and the two most closely related wild forms are included in the section *Cerealia*. Åberg and Wiebe (1946) classify the cultivated barleys into three species on the basis of brittleness of the rachis and number of kernel rows on the spike. They also give detailed descriptions of taxonomic characters for growth characteristics of the plant, spike, and kernel and include keys for identification of varieties commonly grown at that time. Plant and growth characteristics such as spring or winter, time of heading, hairiness of leaf sheaths, and collar shape at the node beneath the spike are relatively constant factors. Spike characteristics such as stigma hairiness, number of rows of kernels, hairiness of rachis edges, length of outer glume awns, and nature of the lemma awn or other appendages are considered most useful in

identifying varieties. Kernel characteristics, evident in threshed samples, are also useful, and will be discussed briefly in a later section.

Most of the cultivated barleys have been classified into the two groups, *H. vulgare* L., the six-rowed barleys, and *H. distichum* L., the two-rowed types. Typical examples are given in Figure 19.

In the common six-rowed barleys, three kernels develop at each rachis node. The median kernel is slightly larger than the lateral kernels on each side and is symmetrical in shape. The two lateral kernels are twisted. The twist is more pronounced at the attachment end of the ker-

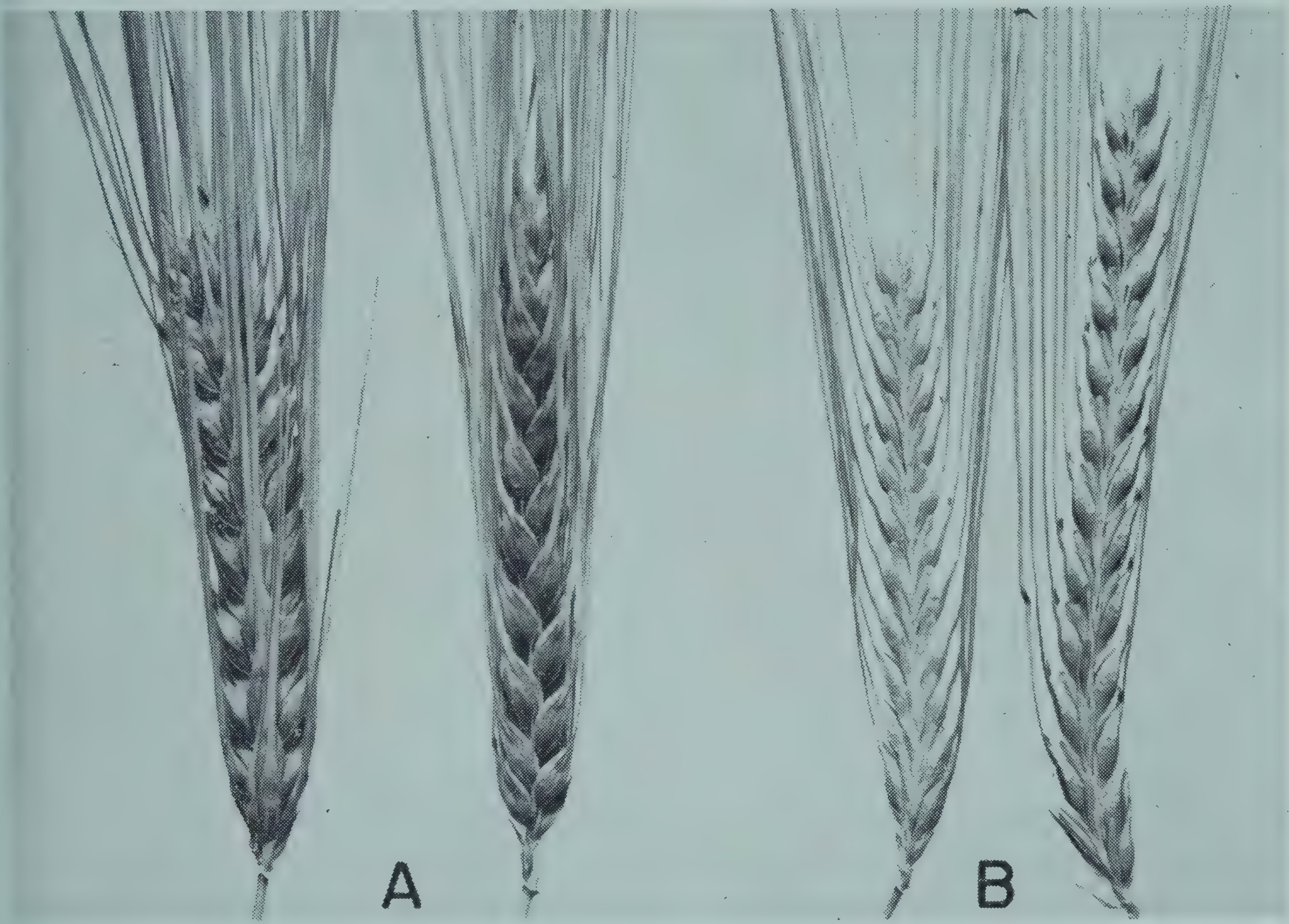

FIG. 19. TYPICAL HEADS OF COMMONLY GROWN BARLEYS
(A) Six-rowed *Hordeum vulgare* (B) Two-rowed *Hordeum distichum*

nel. The Manchurian type six-rowed barleys commonly grown in the northcentral part of the United States and important as malting barleys are typical of *H. vulgare* L. They have medium-size kernels weighing approximately 34 mg. Varieties with rough or smooth awns, white or blue aleurone color, and nodding or erect heads are included.

Also included in this group are the Coast-type barleys commonly grown in California, as typified by the Atlas varieties. They are characterized by large, long kernels weighing about 45 mg., having relatively thick hulls that tend to obscure the blue color of the aleurone when present. Varia-

tions in color of aleurone and in length and shape of heads and kernels are found in representatives of this group.

In the common two-rowed group, the lateral florets are sterile and greatly reduced. Only one row of kernels develops on each side of the spike. The kernels are all symmetrical and more uniform in size than those of six-rowed varieties, but the kernels that develop at the base and the tip of the spike are often somewhat smaller than those in the center. The varieties Hannchen and Hanna, grown in the intermountain and western areas of the United States, are typical of this group. Medium long, relatively plump kernels weighing 35 to 45 mg., with thin, white, finely wrinkled hulls and with white aleurone are typical of the group. Except for kernel shape and size, variation in characters within important varieties of this group is less than for the six-rowed groups.

Åberg and Wiebe (1946) gave the name *H. irregulare* to a newly defined species of barley. The median florets are fertile, but the proportions of fertile, sterile, or wanting lateral florets vary considerably. This type has been found in Abyssinia and probably originated there. The species is not represented by commercial varieties.

PRODUCTION STATISTICS

Geographical Distribution of Production

In the World.—Over the five-year period 1952 through 1956 the estimated world production of barley averaged 2.8 billion bushels. This compares with an average of 2.4 billion for the five-year period 1935 through 1939 and 2.2 billion for the period 1945 through 1949. The last five years (1952 through 1956) for which records were available showed a significant increase over earlier periods, and a small gradual increase occurred each year.

Considering areas of the world, Europe produced the largest quantity of barley from 1952 through 1956 followed in order by Asia, North America, Africa, South America and Oceania. Yearly production in Europe varied between 800 and 1,000 million bushels with appreciably larger amounts produced in 1955 and 1956 compared with the previous three years. The leading barley producing areas of Europe were France, United Kingdom, Denmark, Western Germany, and Spain in the order of average production for the five-year period 1952 through 1956. Barley production in Asia averaged between 800 and 900 million bushels over the five years. There was no great increase in production in Asia in 1955 and 1956 in contrast to Europe and North America. Canada produced more barley in 1952 and 1953 than the United States, but usually the reverse is true.

In the United States.—Barley production in the United States in 1957 was estimated at almost 436 million bushels, which was 16 per cent above the 1956 crop and 49 per cent above the 1946 through 1955 average. The ten largest producing states in order of decreasing production were California, North Dakota, Montana, Washington, Oregon, Minnesota, Idaho, Colorado, Kansas, and South Dakota. Over the 12-year period 1946 through 1957 barley production in California averaged slightly higher than that in North Dakota. In 1956 North Dakota produced almost 7 million bushels more than California.

The statistics for 1957 may overemphasize the westward trend in barley production that started about 1829, according to Weaver (1950). In 1957, 54 per cent of the total production for the United States was in eight Western States, the six listed previously plus Arizona and Utah. Only 27 per cent of the crop was produced in the seven North Central States usually considered as midwestern malting barley-producing states. The continued dominance of the Red River Valley barley area is indicated by the large production in North Dakota, Minnesota, and South Dakota.

Chronological Data on Production in the United States

The number of acres harvested, average yield per acre, and total production of barley in the United States for the 19-year period 1939 through 1957

TABLE 12

CHRONOLOGICAL DATA FOR BARLEY ACREAGE, YIELD AND PRODUCTION IN THE UNITED STATES, 1939–1957

Year	Area	Yield per Acre Harvested	Production
	1,000 Acres	Bushels	1,000 Bushels
1939	12,739	21.8	278,198
1940	13,525	23.0	311,278
1941	14,276	25.4	362,568
1942	16,958	25.3	429,450
1943	14,900	21.7	322,913
1944	12,301	22.5	276,275
1945	10,454	25.5	266,994
1946	10,380	25.5	265,059
1947	10,955	25.7	281,868
1948	11,905	26.5	315,537
1949	9,872	24.0	237,071
1950	11,155	27.2	303,772
1951	9,424	27.3	257,213
1952	8,236	27.7	228,168
1953	8,680	28.4	246,723
1954	13,370	28.4	379,254
1955	14,564	27.5	401,225
1956	12,940	29.1	376,873
1957	15,000	29.0	435,695
19-year average	12,191	25.8	314,533

are given in Table 12. No trend is evident in harvested acreage or production over this period. Increased seeding during World War II is evident, but a low yield per acre in 1942 resulted in slightly lower production in that year than in 1957. After the war, barley acreage and production held constant for a time but were reduced to new lows in 1949, 1951, 1952, and 1953. The lowest recorded acreage and production were in 1952. The exact cause of this drop is not clear, but it may have resulted from unfavorable growing and harvesting conditions which, in turn, would result in low prices.

The abrupt increase in acreage and production in 1954 coincides with wheat acreage restrictions, and the sowing on land normally devoted to wheat. This also explains, at least in part, the large increase in production in Montana, Washington, Oregon, and California since that date. The marked increase in average yield per acre in 1956 and 1957 was caused by the increased production in Western States, where yields are relatively high.

PRODUCTION METHODS IN THE UNITED STATES

Growing the Crop

For best yields of good quality grain, barley should be sown early in a well-prepared seedbed on adequate but not excessively fertile soil. In many areas of spring barley production, fall plowing of the land is recommended. This covers previous crop residues which may harbor disease organisms and permits early seeding the following spring. Barley is grown successfully on spring-plowed or disked land, but spring plowing may delay seeding date and thus increase weed competition and disease problems.

Rotation of crops is generally good practice, and barley is no exception. Where barley follows a cultivated crop, such as corn, weed competition is reduced and residues of heavy fertilization of the corn are usually adequate for good yields. However, barley following corn may be scabby unless the cornstalks are plowed under. Where barley is planted on plowed legume hay land, excessive soil nitrogen may result in lodging. In lower rainfall areas where summer fallowing is practiced, barley usually is sown on fallow land which supplies more moisture and fertility.

Barley is seeded with grain drills at a rate of about one and one-half bushels per acre. This rate may be increased or decreased somewhat depending upon soil moisture and fertility, time of seeding and prevalence of weed seeds. Where grasses or legumes are seeded with barley as a companion crop, the seeding rate may be reduced to lessen its competition with the grass or legume seedlings. The depth of seeding should be from

$^1/_2$ to $1^1/_2$ inches. This will depend upon soil type and condition and surface moisture supply.

The use of fertilizers for barley is increasing. Phosphorus and potassium are rather commonly applied to some soils, but frequently increased yields have resulted from nitrogen applications of 25 to 50 lbs. per acre drilled with the grain. In the production of barley for malting, heavy applications of nitrogen may increase barley protein and reduce malting quality. Heavy nitrogen fertilization often results in lodging of the plants, and this interferes with normal development of the grain.

The time of seeding varies with location. Most winter barleys are sown between September 15 and the last of October. Spring barleys are sown from April 1 to May 15, or about as early as the land can be prepared. In California, barleys with a spring-growth habit are sown from late October until mid-January, and thus are grown as a winter crop.

Harrowing of barley to control weeds is not beneficial to the crop. When broadleafed weeds develop early before the shade from the grain leaves prevents their rapid growth, spraying with commercial formulations of 2,4-D is now commonly used. The most favorable time to spray for weed control is when the grain is 8 to 12 inches tall.

Harvesting

Barley should be harvested only when the grain is fully ripe. This is especially important in the growing of barley for malting. When the straw is completely yellowed, the kernels feel dry to the hand and snap when bitten, the grain moisture will usually be between 14 and 16 per cent. Grain harvested at 14 per cent moisture or less will usually keep in the bin in the cooler parts of the United States.

Combining is the cheapest method of harvesting and is used almost exclusively in large acreage production. If ripening and drying conditions are good, the standing grain will be combined directly. In fields where ripening is not uniform or where many green weeds are present, the grain is cut with a windrower and laid in swaths on a long stubble. After one or more days of drying, a pickup attachment elevates the grain to the combine for threshing. Grain in windrows deteriorates more rapidly than standing grain during rainy weather, but will be of better quality if no rain occurs.

Some grain is cut with a binder in areas in which barley is grown in small acreages, such as Wisconsin. The bundles are shocked in the field to dry and later hauled to a threshing machine for separation. This permits piling the straw in a convenient location. However, if small mobile baling equipment is available, the straw from the combine can be picked up, baled, and stored in this manner for feed or bedding.

With either method of harvesting, the separator must be properly adjusted to thresh the grain cleanly without excessive skinning or breaking of the kernels. This is especially important for barley produced for seed or malting, as damaged kernels will not germinate properly.

Storage

At present, most barley is stored in bulk in bins of various sizes from a few hundred to many thousand bushels. For safe storage of large quantities for long periods grain should have a moisture content of less than 13 per cent according to Tuite and Christensen (1955). Freshly harvested grain with a moisture content above 14 per cent may heat and go out of condition. Usually moisture is not evenly distributed in harvested grain, and small areas may be wet enough to permit development of mold. This localized mold growth raises the temperature and moisture content still higher and, if it is allowed to continue, the entire lot may heat and go out of condition. Only moderate development of storage molds and increases in temperature and moisture will destroy the germination ability of barley and give it a musty odor if allowed to continue. Barley that is to be used for seed or malting requires close watching and special care in storage.

Freshly harvested grain is usually watched carefully and, if a significant rise in temperature is noted, it is moved from one bin to another which cools the grain and mixes the damp and dry portions. If very wet it should be dried artificially. Elevators for storage of malting barley are equipped with temperature-recording facilities at frequent intervals in the bins to aid in detecting the start of heating. A few large growers are installing driers to reduce the moisture of directly combined grain to a safe storage moisture. Great care and control of conditions, especially temperature, are required to prevent destruction of germination capacity of the grain.

UTILIZATION OF BARLEY IN THE UNITED STATES

Animal Feed

The major use of barley in the United States is for animal feed. Over the ten-year period 1947 through 1956 approximately 53 per cent of the annual production of barley was used for this purpose. A comparable value for the previous ten-year period 1937 through 1946 was 66 per cent, but this included the war period when larger quantities were needed for animal feed. The grain may be used in blends with other feed materials for all farm animals but is especially prized as a feed for bacon hogs and for sheep and lambs for show purposes.

The grain is ground and mixed with other concentrates or grains for

feeding or may be steamed and rolled to produce a flake. Recently, Dinusson (1957) in North Dakota found that the pelleting of barley increased its palatability and efficiency as a feed for hogs. Malt sprouts, brewers' grains and distillers' grains are important barley by-product feeds for livestock from the malting, brewing, and distilling industries, respectively.

Industrial Uses

The major industrial use of barley is the production of malt. In the ten-year period mentioned in the preceding section, the quantity used for this purpose varied from 22 to 39 per cent of the crop, the proportion depending upon total production and quality of the grain. The average utilization for this purpose was 32 per cent. Total usage varied from a low of 88 million bushels in 1954 to a high of 101 million bushels in 1950.

Specific varieties of three types grown in definite areas of the country are usually used for malting. The six-rowed Manchuria type, exemplified by the varieties Kindred, Traill, and Montcalm, and grown in the North Central states supplies 80 to 90 per cent of the barley for malting. In years when the production and quality of barley from this area are low, Canadian barley is imported to meet the requirement. About 10 million bushels of the two-rowed varieties Hannchen and Hanna, grown in specific areas of Oregon, California, Washington, and Idaho, are required annually for malting. Somewhat smaller quantities of the six-rowed Coast-type barley Atlas grown in the valleys of central California are used for malt production. In the Western States, production of good quality grain is usually in excess of the amount required. In recent years, about 85 per cent of the malt production is used for beer manufacture, slightly less than ten per cent for alcohol and whiskey, and somewhat over five per cent for food uses.

Human Food

The uses of barley and barley products according to Phillips and Boerner (1935) are as listed on page 86.

The many food uses of barley and malt excluding malt beverages utilize somewhat less than ten million bushels of barley annually. An estimated three million bushels is used for production of pot and pearl barley, and small quantities of barley flour are used for baby foods. Two-rowed varieties grown in western areas that produce large plump kernels are preferred for pearling.

Food uses of malt are numerous, but the quantities used are small. A number of types of malt syrups for specific uses, malted-milk concentrates, enzyme supplementation of wheat flour, and breakfast foods are typical

Uses of Barley and Barley Products

Feed	
Livestock	
Poultry	
Export	
Feed	
Malting	
Pearling	
Pot barley	for soups and dressings
Pearled barley	for soups and dressings
Flour	
Feed	
Milling	
Flour for baby foods and food specialties	
Grits	
Feed	
Malting	
Brewers' beverages	
Brewers' grains for dairy feeds	
Brewers' yeast for animal feed, human food, and fine chemicals	
Distillers' alcohol	
Distillers' spirits	
Distillers' grains	for livestock and poultry feeds
Distillers' solubles	for livestock and poultry feeds
Specialty malts	
High dried	for breakfast cereals, sugar colorings, dark beers, and coffee substitutes
Dextrin	for breakfast cereals, sugar colorings, dark beers, and coffee substitutes
Caramel	for breakfast cereals, sugar colorings, dark beers, and coffee substitutes
Black	for breakfast cereals, sugar colorings, dark beers, and coffee substitutes
Export	
Malt flour for wheat flour supplements, human and animal food products	
Malted milk concentrates for malted milk, malted milk beverages, and infant foods	
Malt syrups for medicinal, textile, baking uses, and for breakfast cereals and candies	
Malt sprouts for dairy feeds, vinegar manufacture, and industrial fermentations	

examples. As malt is used for flavor or enzyme action in most cases, relatively low concentrations are employed.

COMPOSITION OF BARLEY AND QUALITY TESTS

Structure of Barley Kernel and Methods for Identification of Varieties

A typical hulled barley kernel from the outside inward is composed of lemma and palea enclosing and cemented to the caryopsis. The rachilla lies within the crease of the kernel near the base and on the ventral or

FIG. 20. MEDIAN AND LATERAL KERNELS OF MIDWESTERN SIX-ROWED BARLEY VARIETY KINDRED

palea side. It is covered with long or short hairs. The lemma is five-nerved and somewhat angled at the nerves. The lateral and marginal nerves may have numerous or few small teeth or may be smooth. The lemma may have a depression consisting of a transverse crease at its base just above the point of attachment. The caryopsis is composed of pericarp, integuments, starchy endosperm, and germ. The outer layer of the endosperm is made up of the aleurone cells. In blue barleys, the anthocyanin pigment is blue in the alkaline aleurone cells, while the same pig-

FIG. 21. MEDIAN AND LATERAL KERNELS OF WESTERN SIX-ROWED BARLEY VARIETY ATLAS

ment in the pericarp or hull appears as red. The aleurone of many varieties is colorless.

The germ is partly imbedded in the endosperm at the base of the kernel on the lemma or dorsal side and is held at an oblique angle to the axis of the kernel. The germ is composed of the embryonic axis, which develops into the seedling at germination, and the adjacent scutellum. The latter structure secretes enzymes that hydrolyze constituents of the endosperm which nourish the growing seedling.

Threshed samples of some major varieties can be distinguished from

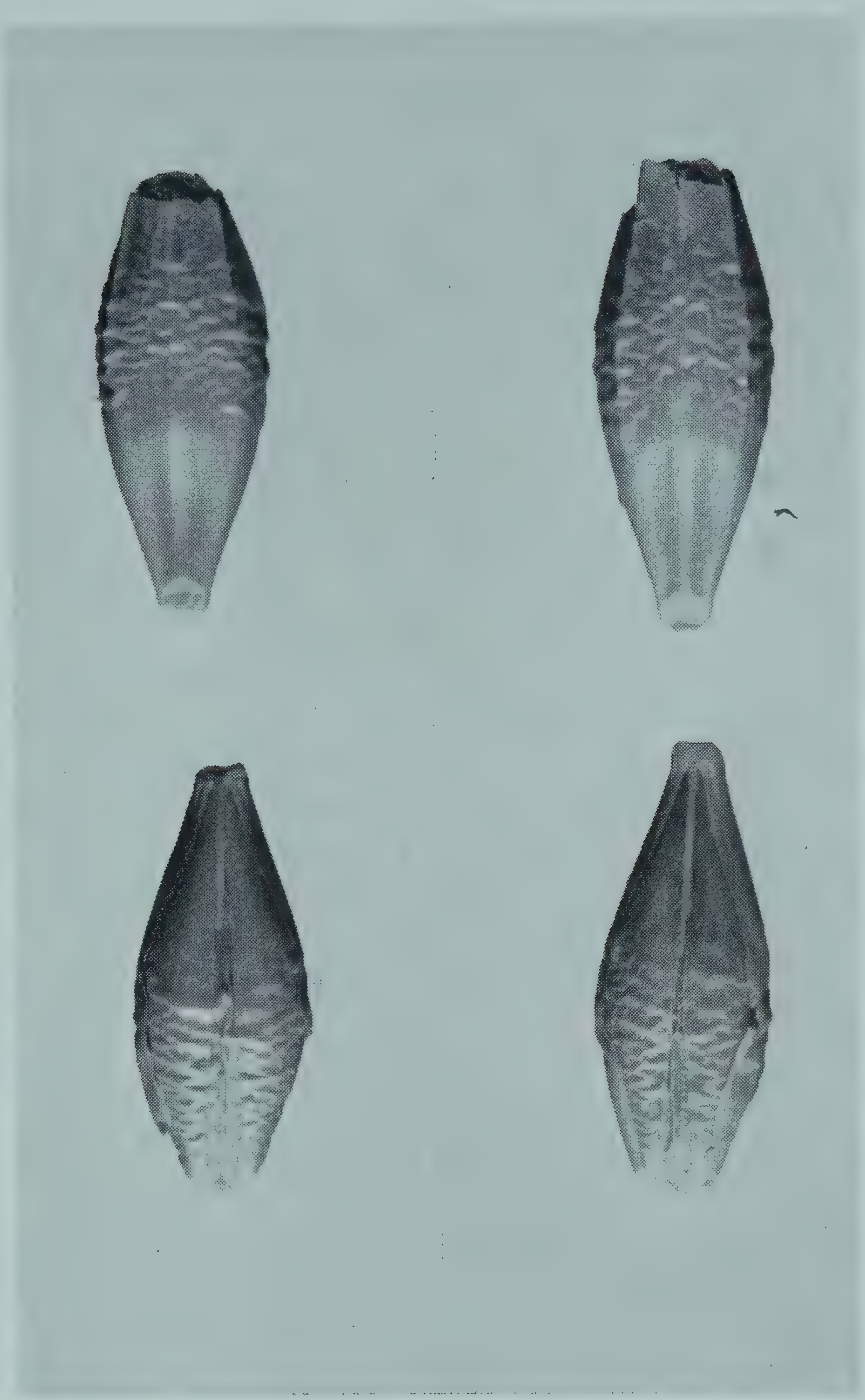

FIG. 22. KERNELS OF WESTERN TWO-ROWED BARLEY VARIETY HANNCHEN

each other with ease, while others can be distinguished only with difficulty. Two-rowed varieties with all symmetrical kernels are distinguished from six-rowed, in which one-third of the kernels are symmetrical and two-thirds are twisted and slightly smaller. Åberg and Wiebe (1946) have further separated the two types into groups on the basis of length of rachilla hairs, length of kernel, kernel color, number of teeth on lateral and marginal lemma nerves, and shape of lemma base. Additional characters are suggested for distinguishing varieties within the groups.

Varietal examples of the three major malting-barley types are described here and illustrated in Figs. 20, 21 and 22. Hannchen has covered kernels,

all symmetrical (two-rowed), white, long-haired rachilla, lemma base with depression, and no to few teeth on lateral lemma nerves and few to several on marginal nerves. The hulls are finely wrinkled.

Kindred has covered kernels, one-third symmetrical, two-thirds twisted (six-rowed), short to midlong white kernels, short-haired rachilla, rough awns, numerous teeth on lateral and marginal lemma nerves.

Atlas has covered kernels, one-third symmetrical, two-thirds twisted (six-rowed), long blue kernels, short-haired rachilla, numerous teeth on lateral and marginal lemma nerves. The three varieties described above could be easily distinguished from one another in threshed grain samples, but distinguishing Kindred from the feed variety Tregal, which falls in the same classification group, is very difficult. Very recently, Malting Barley Improvement Association (Anon. 1957) published a barley variety dictionary to aid in identification of commercial varieties.

Chemical Composition for Feed and Food Uses

The major use of barley is for animal feed. Typical proximate analyses of three types as given by Dickson and Kneen (1952) have been modified somewhat in Table 13. Feed barleys from drier production areas would be slightly lower in kernel weight, higher in protein, and proportionately lower in nitrogen-free extract. Although barley is used primarily as a

TABLE 13

TYPICAL PROXIMATE COMPOSITION OF THREE TYPES OF BARLEY[1]

Barley Type	Kernel Weight	Hull	Protein	Fat	Starch	Fiber	Ash	Nitrogen-Free Extract
	Mg.	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Midwestern six-rowed	34	12	12	2.0	58	5.7	2.7	66.6
California six-rowed	45	14	11	2.0	58	6.6	3.0	65.4
Western two-rowed	40	10	10	2.0	60	5.2	2.5	72.3

[1] Adapted from a section by Dickson and Kneen in Vol. 8 of the Encyclopedia of Chemical Technology, copyright 1952 by Interscience Encyclopedia, Inc., New York.

source of carbohydrate, the protein content is of considerable importance. According to Orr and Watt (1957), barley contains significant amounts of 19 amino acids, but in common with other cereal grains is low in the essential amino acids lysine and methionine. The nine essential amino acids in pure varieties of wheat, barley, and oats grown on six soil types were determined by McElroy *et al.* (1949). The fraction of the total nitrogen contributed by lysine decreased as the total nitrogen increased. These workers found that the proteins from oats and barley were some-

what higher in lysine than those from wheat. Recent work has indicated increased growth rates of animals when barley is supplemented with lysine.

Average percentage carbohydrate composition of European two-rowed barleys as given by Preece (1954) is: starch 62.0; reducing sugars 1.0; nonreducing sugars 1.5; pentosans 9.5; and cellulose 5.0. In six-rowed barleys, one would expect to find somewhat lower quantities of starch and larger amounts of pentosans and cellulose.

In studying the nutritional value of western-grown barley for young chicks, McGinnis (1958) recently showed increased growth rate and food efficiency when ground barley is steeped in water, dried, and incorporated into the feed. This effect has been ascribed to increased carbohydrate utilization, and supplementation with crude alpha-amylase and other enzymes has given a similar response. The exact cause of this response must await further study, for rapid production of enzymes in steeped ground grain appears to be unlikely.

According to Schultz *et al.* (1941), barley is slightly higher than wheat and slightly lower than oats in thiamin content. Ranges in values over a relatively large number of samples in micrograms per gram were wheat 4.2 to 7.3, barley 4.7 to 9.2, and oats 4.8 to 10.3. Davis *et al.* (1943) found similar values for wheat and barley in thiamin, 5.6 and 5.7, respectively, and in riboflavin, 1.0 and 0.9 respectively; higher values for barley than wheat in nicotinic acid, 86.3 and 58.6 respectively; and higher values for wheat than barley in pantothenic acid, 7.9 and 4.5 microgram per gram respectively. Malting increased riboflavin content about threefold but had only a small influence on the other B vitamins. Seven barley samples varied in choline content from 0.96 to 1.20 mg. per gm., according to Glick (1945). Similar values were found for oats and flax, but slightly lower quantities for wheat.

Physical and Chemical Requirements for Malting

Malting is the second largest use for barley and requires almost 100 million bushels annually. Significant quantities of wheat and small amounts of rye are malted in the United States, but the major malting grain is barley. Tradition may have contributed somewhat to this use, but the major reasons are related to the structure, composition, and physiology of the grain. The barley grain is somewhat firmer in structure and softens less than wheat and rye during the steeping and germination phases of malting. The attached hulls protect the plumule of the germ as it grows under the hull until the tip of the kernel is reached. In skinned kernels where the plumule is exposed it is likely to be damaged, and normal malting and modification of the kernel may be interrupted. This

same situation exists in wheat and rye which thresh free from the hulls.

Good malting barleys should be plump and well filled, moderately low in protein, and capable of vigorous uniform germination. They should be free of disease, excessive staining or weathering, and high-temperature or moisture damage during storage. During the malting process, the barleys should be capable of desirable physical and chemical modification, activation and production of desired levels of several enzyme systems all with a minimum loss of dry material through respiration and rootlet development. Adequate hydrolysis of proteins and starch to permit the development of desirable flavor during kilning of the malt by the browning reaction, and without development of excessive color, is essential.

Tests for Malting Quality

The malting quality of hybrid selections or new varieties can be predicted with a reasonable degree of accuracy by determination of barley kernel weight, kernel size assortment, using standard sieves, and barley protein content. Barley extract is determined by using a supplementary source of enzymes to hydrolyze the barley compounds. Beta-amylase exists partly free and partly in a bound form in barley, and the latter can be freed in finely ground samples by a proteolytic enzyme such as papain or by sulfhydryl compounds. Extraction with papain is employed in the determination of diastatic power.

A more reliable evaluation of quality requires experimental malting of the barley. Rate and uniformity of water absorption in the steep and germination, as well as the percentage loss of dry matter in the process, can be obtained. The malt is analyzed for extract or total soluble constituents after mashing with water under a prescribed temperature and time schedule. Filtration of the mash gives an extract, called wort. The amount of soluble nitrogen in the wort in relation to that in the malt serves as an indication of protein breakdown during malting and mashing and is a rough measure of proteolytic activity. Beta-amylase is freed during malting and can be extracted directly from the ground malt. Alpha-amylase, which is essentially non-existent in normal barley, is synthesized during malting and can be extracted and determined. Standardized procedures for the methods mentioned have been developed by the American Society of Brewing Chemists (Anon. 1958). Typical analyses of malts from the three types of malting barley as reported by Dickson and Kneen (1952) are given in Table 14.

Until more complete information is available on the chemistry of barley and the biochemistry of the malting and brewing processes, final quality evaluation of barley requires experimental malting and pilot-plant brewing of the malt. The best and most widely used method for barley quality

TABLE 14

TYPICAL ANALYSES OF MALTS FROM THREE TYPES OF BARLEY[1]

Analytical Item	Midwestern Six-Rowed	California Six-Rowed	Western Two-Rowed
Kernel weight, dry basis, mg.	29.0	39.0	37.0
Growth, length of acrospire			
0–1/4, per cent	2	3	2
1/4–1/2, per cent	3	8	4
1/2–3/4, per cent	9	15	10
3/4–1, per cent	83	74	83
Overgrown, per cent	3	0	1
Assortment:			
on 7/64 screen, per cent	28	68	85
on 6/64 screen, per cent	54	26	10
on 5/64 screen, per cent	16	6	1
through screen, per cent	2	0	0
Moisture, per cent	4.5	4.7	4.5
Extract, fine grind, dry basis, per cent	76.0	76.4	80.5
Extract, coarse grind, dry basis, per cent	74.0	74.0	79.0
Difference, per cent	2.0	2.4	1.5
Color, 1/2 in. cell, Lovibond S. 52	1.4	1.3	1.0
Total protein, dry basis, per cent	12.0	11.0	10.0
Soluble protein as per cent of total	38.0	32.0	38.0
Diastatic power, dry basis, °L	125	60	100
Alpha-amylase, dry basis, 20° units	21	18	20

[1] Adapted from a section by Dickson and Kneen in Vol. 8 of the Encyclopedia of Chemical Technology copyright 1952 by Interscience Encyclopedia, Inc., New York.

evaluation is by observations on the processing performance, analysis of resulting worts and beers, and determination of characteristics of the final beers. The malting and brewing industries are cooperating with State and Federal workers in an extensive program for the development and evaluation of improved malting barleys for the United States and Canada. Methods for barley quality evaluation were recently reviewed by Dickson and Burkhart (1956).

Composition in Relation to Malting

Preece (1954) recently reviewed this subject, and a few of the major constituents will be discussed briefly here. The four groups of proteins as given by Osborne more than 60 years ago have been shown by modern methods to be composed of a much larger number of compounds. Salt-soluble barley globulin has been shown to be a mixture of four, designated as alpha, beta, gamma, and delta. Barley appears to be the only cereal that contains beta and delta globulin. The former is resistant to modification during malting and brewing and may be important in formation of hazes in beer. Water-soluble albumin and alcohol-soluble hordein have also been shown to be mixtures of several proteins. Beta-amylase is a constituent of the albumin fraction, while alpha-amylase appears to be in the globulin group. The alcohol-soluble hordein fraction is most completely

degraded during malting, forming soluble nonprotein substances. Eighteen to twenty amino acids have been found free in barley, and the quantity of all increases greatly during malting.

Barley starch has been shown to be similar to that from other cereal grains. Recent work has shown that the hemicelluloses and especially the barley gums may be important in barley and malt quality.

Many different enzyme systems are important in the respiration and germination of barley and are produced during the malting process. It would appear that only beta-amylase is abundant in normal barley. It is also high in wheat and rye, but is much less abundant in oats. Alpha-amylase is absent or nearly so in barley, but is produced during germination by all cereal grains.

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H. L. Shands

Rye

HISTORY OF RYE CULTIVATION

Rye is among the less important cereal crops of the Americas, but it is of major importance in Europe where it is used as a bread grain. The exact time that rye was brought under cultivation is not known. It is thought to be one of the crops more recently domesticated. Whether it is more recent than the hexaploid bread wheats is a matter of speculation. Rye seeds have not been found in the excavations of the cliff dwellers or early Egyptians nor was the crop pictured on early coins as was barley and emmer. Vavilov (1926) thought that cultivated rye arose from the rye-weed originally growing in crops of barley and wheat. Cultivation of the crop probably started before the Christian era.

As cited by Kranz (1957), Zhukovsky and Schiemann, suggested that cultivated rye may have arisen from the two independent sources, *Secale ancestrale* Zhuk. and the wild types of *Secale montanum* Guss. Kuckuck and Kranz (1957) after studying Iranian rye populations, suggested that cultivated rye may have originated from several sources as hypothesized by Roshevitz (1947). He indicated that perennial wild ryes could have given rise to annual wild ryes which in turn could have been the forerunners of cultivated rye.

Vavilov stated that rye was undoubtedly introduced into cultivation simultaneously and independently at many localities. He found greatest botanical diversity in Afghanistan, Persia, Transcaucasia, Asia Minor and Turkestan, finding as many as 18 botanical varieties in Afghanistan. Zhukovsky (cited by Vavilov) found 14 varieties in Georgia and Armenia. The weed-rye of Afghanistan, Persia, and Turkestan had types with closely investing lemmas, non-shattering spikes, and had adpressed awns. The weed-ryes of Armenia and Asia Minor had spreading awns with non-invested kernels that resembled cultivated ryes.

The cultivated winter rye may have entered Europe from two sources according to Vavilov. One was from Transcaucasia and the other from Turkestan, Afghanistan and adjoining regions. Then it probably spread northward during times when cultural practices were unrefined and probably was often sown in preference to wheat because rye could withstand more adversities.

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Adversity is no stranger to rye even to the present day. Vavilov stated that the peoples of Persia and Afghanistan considered rye to be a noxious weed and found it difficult to control. One reason it was considered noxious was that the seeds were difficult to separate from that of wheat. As late as 1925 the Board of Agriculture of northern Caucasus recommended mowing down rye while in bloom, but cautioned not to injure wheat. Farmers who adopted this practice in 1925 were freed of taxes. Such an inducement in the western world today might have far-reaching effects in reducing this crop.

Because of its competitive ability among other plants, rye may have increased at the expense of wheat acreage in northern Europe for a period of several centuries until better adapted wheats or better cultural practices were found for wheat. For more than 100 years rye has been losing acreage in European countries and the end may not yet be in sight. Jasny (1940) pointed out that the use of rye for bread permitted many economies in baking, merchandising, etc.; yet the taste for and desire for rye bread was diminishing in heavy rye-producing European countries. Ljung (1948) indicated that Sweden grew rye and wheat in a ratio of 4 to 1 at the beginning of the twentieth century but that by 1948 wheat production was about equal to rye in that country. The trend has been the same in the western hemisphere. Yet there are vast areas in the Old World where rye is certainly the most dependable grain crop and undoubtedly it will remain popular.

Rye was introduced into northeastern United States during colonial times by English and Dutch settlers according to Collier (1949). From this area rye spread southward and westward where acreage rose for a period of years, but more lately receded.

CHRONOLOGICAL DATA OF RYE PRODUCTION

World Production

Total world production of rye for the past 25 years has averaged somewhat more than 1.5 billion bushels according to Agricultural Statistics of the U. S. Department of Agriculture. Since the legal weight for rye is 56 lbs. per bushel, rye production may be compared easily with that of corn and wheat, but there needs to be an upward adjustment of bushels if compared with rice, barley or oats.

For the 3-year period of 1953–55, the average world production was almost 1.5 billion bushels. Previous to that time, there was moderate fluctuation notably during, and immediately after, the second World War. The average production from 1925 to 1940 was somewhat more than 1.7 billion bushels. In general, total production of rye has remained fairly

constant but with a slight downward trend during the past ten years.

Russia produces the greatest amount of rye annually—in fact, this country produces about half of the total world output. However, rye is rather intensively cultivated in Poland, West Germany, and other northwestern European countries. The United States and Canada produce only a small percentage of the world supply.

Other countries producing a significant amount of rye are France, Spain, Netherlands, Argentina, Austria, and Denmark. Turkey produces a quantity almost equal to that of the United States. Argentina's production of rye has fluctuated pronouncedly, ranging from 3.2 million bushels in 1951 to more than 52 million bushels in 1952.

Production in the United States

Production of rye in the United States has varied over a wide range since beginning records in 1869. Production in 1869 was near 16 million bushels; it gradually rose to 29 million bushels in 1909, increased rapidly until 1919, and then reached a high point of more than 101 million bushels in 1922. This bulge in production may have been partly accounted for by several rust years for wheat during World War I. The average production in the United States for the 5-year period 1935 through 1939 was 54 million bushels and for the 5-year period from 1939 to 1945 was 39 million bushels. This indicates a downward trend in interest in rye in the United States.

The North Central states produce the greatest quantity of rye within the United States. During the period of 1937 through 1946 there were six states in this area that produced more than a million bushels for the ten-year average. South Dakota and North Dakota, producing nearly 7 million bushels each, were the two leading states, while Minnesota and Nebraska were almost equal in production but definitely below that of the Dakotas. Wisconsin ranked fifth and was followed by Indiana and Michigan. Production fluctuated in these states as shown by North Dakota's growing more than 16 million bushels in 1942 as compared to the 11 million bushel average from 1928 to 1932.

Acre Yields

Acre yields of rye reach a low point in the Union of South Africa where 5 to 7 bushels per acre is the average. In contrast to this, Belgium, Denmark, and Holland averaged more than 40 bushels per acre in the 1952 to 1954 period, according to Agricultural Statistics of the U. S. Department of Agriculture. Wheat outyields rye by small to large margins in these countries. It is interesting to note that there is more rye than wheat acreage in both the Netherlands and Germany.

BOTANICAL CLASSIFICATION OF RYE

The genus *Secale* belongs to the tribe *Hordeae* of the grass family. The inflorescence of rye is a spike or "ear" that resembles that of wheat. The spikelets are arranged alternately and are placed flatwise against a zigzag rachis. Most forms of *Secale* have spikes that taper toward the tip. Spikelets are usually two-flowered except under thin planting or fertile soil conditions. They are composed of two thin, narrow glumes that subtend the two florets each of which is partly enclosed by a narrow lemma and palea. Each floret contains 3 stamens and a pistil which, after fertilization, develops into a one-seeded fruit known as the caryopsis and is called the kernel or grain. All domesticated rye grain threshes free.

Photo by E. H. Herrling, Courtesy of Wisconsin Agr. Expt. Sta.

FIG. 23. RYE *Secale cereale* L. IN FLOWER

Note exposed stamens after shedding pollen

Key to *Secale* Species

Antropov and Antropov (1948) presented a synopsis of species and botanical varieties of the genus *Secale* including the key on p. 101. (Flaksberger *et al.* 1939).

These workers classified 9 species as having various degrees of rachis shattering and one having a "tough" or non-disarticulating spike, the latter being *Secale cereale* L. Of the 10 species, 6 were perennial, and 4 annual. S. *cereale* was described as having winter or spring annual forms. They described 28 botanical varieties of S. *cereale* that do not disarticulate and 18 that shatter. They also described 94 sub-varieties within the "*vulgare*" grouping of Koernicke. Their basis for separating these species, varieties, and sub-varieties were glume shape, awn type, spike density, lemma pubescence, color of lemma, ligule characteristics, and auricle color. In regard to species grouping Kranz (1957) pointed out that Schiemann divided *Secale* into two groups; I., the wild types having the following species: S. *sylvestre*, S. *montanum*, and S. *africanum*, and II., those being cultivated: S. *fragile* and S. *cereale*. Roshevitz (1947) divided the *Secale* genus into *Silvestria*, *Kuprijanovia*, and *Cerealia* groups. He recognized all of the species listed in the key above in addition to S. *daralagesi* Thum., S. *afghanicum* (Vav.) Roshev., S. *dighoricum* (Vav.) Roshev., and S. *segetale* (Zhuk.) Roshev.

Cultivated Varieties Grown in the United States

Cultivated agricultural varieties are less numerous than in other small grain crops. These varieties are plastic and are variable because the crop is cross pollinated to a high degree.

The Abruzzi variety of Italian origin has been grown widely in the Southern states for a long time. Elbon and Gator are new, the latter having been described by Chapman *et al.* (1956). Balbo was introduced into the United States in 1932 according to Mooers (1933); it has been popular in the central tier of states. Rosen has been grown even longer in this area and Michigan. Spragg and Nicolson (1917) reported on the origin of Rosen.

The Dakold variety has long been considered winterhardy. It was distributed by the North Dakota Agricultural Experiment Station in 1922. Pierre is grown in South Dakota. Imperial with light amber kernels was once known as "white" rye. It was replaced by Adams which was distributed by the Wisconsin Agricultural Experiment Station in 1953. Caribou, distributed in the same year in Minnesota, gave promise of good yields according to Robinson and Koo (1954). This variety is a sister

Key for species determination[1]

I. Spike breakable, disarticulates at maturity.
  A. Glumes with awns 1.5 to 2.3 cm. long, 2–3 times as long as the glumes. Annual plants, short. . . . . *S. silvestre* Host
  B. Glumes without awns or with short awns (less than 1.5 cm.)
    1. The rachis disarticulates down to the base. Caryopsis laterally compressed. Plants very robust, stems up to 3 meters tall, annual. . . . . *S. ancestrale* Zhuk.
    2. At maturity upper $^1/_3$ to $^2/_3$ of the rachis disarticulates.
      a. Annual plants, short and wild. . . . . *S. Vavilovii* Grossh.
      b. Perennial plants, 60–150 cm. in height.
        X. Plants entirely covered with soft pubescence . . . . *S. ciliatoglume* (Boiss) Grossh.
        XX. Plants glabrous or with pubescence on outer epidermis of lower leaves.
          O. Spikelets small, lemma 9–11 mm. in length.
            o. Glumes unequal; lemmas with very fine and short hairs on the keel. . . . . *S. africanum* Stapf and Hook.
            oo. Glumes equal; lemma always with short hairs. . . . . *S. anatolicum* Boiss.
          OO. Large spikelets, lemma 14–18 mm. long.
            o. Stem 150 cm. tall and 5–6 mm. in diameter. Leaf 1–2 cm. wide. Ligule 3–4 mm. long . . . . *S. Kuprijanovii* Grossh.
            oo. Stem up to 90 cm. in length and 2–3 mm. in diameter. Leaf up to 5 cm. wide with ligule up to 2 mm. in length
              &. Plants grey-green. . . . . . . *S. montanum* Guss.
              &&. Plants with small blue spots . . . . *S. dalmaticum* Vis.

II. Spikes tenacious (tough) (except the variety *afghanicum* Vav., whose spike disarticulates down to the base). Glumes with awns, very seldom without awns. Lemma with awns shorter than the spike. Caryopsis enlarged. Plants spring or winter annuals . . . . *S. Sereale* L.

[1] Apparently original in Russian; translated into Spanish by José Buckevicrus with resumé by Castulo Cialzeta. Translation of Spanish into English by Eduardo Neale-Silva and H. L. Shands.

Photo by E. H. Herrling, Courtesy of Wisconsin Agr. Expt. Sta.

FIG. 24. SPIKES AND KERNELS OF BALBO AND *Tetra Petkus* RYE
Upper left, 2 spikes of Balbo rye
Lower left, 3 enlarged kernels of the Balbo variety. Kernels show incipient sprouting
Upper right, 2 spikes of Tetra Petkus
Lower right, 3 enlarged kernels of Tetra Petkus

of Antelope described by Harrington (1953). Petkus and Tetra Petkus, of European origin, are grown to a limited extent in Canada and the United States. The performance of several important rye varieties tested under Indiana conditions was described by Caldwell *et al.* (1958).

Only a small amount of spring rye is grown in North America. Merced is sown in California and Prolific in other areas.

Varieties Grown in Europe and Russia

One of the most outstanding varieties grown in Europe is Petkus selected out of Pirnaer and Probsteier, Landsort varieties by Dr. F. von Lochow. First selection was in 1881, with first distribution in 1889. From this variety many selections have been made. There is a Petkus spring rye which yields well under favorable conditions, but usually less than winter Petkus.

Other varieties grown in western Europe are von Rumker, Dominant, and Heertvelden, the latter two being distributed in 1953. According to Dorst *et al.* (1955) Dominant was bred from a cross between von Lochow's Short Straw and Brandt's Marion. Heertvelden, from the cross between Ottersume and Petkus, is resistant to eelworm (nematode). Some of the varieties grown in Northwestern Europe are Star, Steel, King's II, and Sangaste.

Nuttonson (1958) studying climate relationships of rye in North America, Poland, Czechoslovakia and the Soviet Union stated that the most widely distributed varieties in Russia were Vyatka, Vyatka 2, Vyatka Moskovskaya, Kazanskaya and Lisitsina. Vyatka 2, Zazerskaya and Zima were reported to be in great demand in Russia. He also described twelve of the most widely grown varieties in Russia.

The Vyatka variety is grown in all regions of northern and the northeastern parts of the Soviet Union. It is also grown widely in the non-Chernozem belt and in many areas of Siberia where snow persists during the winter.

Improvement

Rye improvement methods have varied because no well established method has been accepted widely. Nearly every variety was produced by a slightly different breeding method. Mass selection in one form or another was the basis for originating varieties several decades ago. Varieties depend somewhat on the breeder's concept as to the type to which they should conform. Close breeding was used to establish some varieties while others have been derived by compositing residue seed lots of plants that were progeny-tested after close selection. Others have been purified by removing undesirable portions of the population. The Pierre variety was developed by compositing 16 inbred lines isolated from Dakold and Swedish rye varieties according to Grafius (1951). Sprague (1938) used similar procedures in developing Raritan. Inbreeding to isolate superior lines has been attempted by Russian workers as well as those of U. S. and Canada. Cyclic inbreeding after hybridizing inbred lines has resulted in superior inbred lines; but none has equalled the open pollinated sorts for yield and vigor.

Self-sterility has been widely observed though inbred lines with more than 50 per cent self-fertility are now available. Recently Kranz (1957) indicated that an Iranian rye flowered cleistogamously and was moderately self-fertile. Though Leith and Shands (1938) stated that properly chosen inbred lines gave hybrid vigor after being crossed, no method of utilizing this principle has been found. Warren and Hayes (1950) studied rye polycross progenies for yield but did not develop a variety after using this breeding method. Ferwerda (1956) proposed a system of breeding rye whereby two varieties are used for interpollination after clones have been tested and found superior on the basis of progeny tests. Clones found desirable after testing in intravarietal and intervarietal crosses would be increased in isolation and then equal quantities of seed mixed for growing commercial seed.

Ross (1953) gave a history of Tetra Petkus rye which was obtained by doubling the chromosome number by the use of colchicine. This variety has stiff straw, large kernels, broad leaves and delayed heading and ripening. It is grown commercially to a limited extent in Canada and the U.S.A. Brown and Nelson (1957) at Michigan could find little advantage of this variety over diploid Rosen. These workers, as well as Koo (1958), and others, suggested that diploid rye should be isolated from tetraploid rye if good seed set were to be expected in Tetra Petkus. Patterson and Mulvey (1954) comparatively grew Tetra Petkus and von Rumker, a diploid type, and did not find severe seed reduction because of pollen interference. Muntzing (1954) hybridized 3 tetraploid forms and found 18 to 19 per cent yield increase over that of the parents. He used spaced plants for the tests. Because Tetra Petkus is a significant departure in agronomic type from the ordinary diploids, there has been an increased interest in breeding by means of tetraploidy.

Amphidiploids between *Triticum* and *Secale* giving $2n$ chromosome number forms of 56 and 42 have been called *Triticales*. Muntzing (1939) and more recently Sanchez-Monge (1956), Sadanaga (1956) and still others have utilized different *Triticum* species and *Secale cereale* for compounding different *Triticales*. Such types may be produced commercially after further investigation.

GEOGRAPHICAL DISTRIBUTION OF PRODUCTION AND CONSUMPTION

Patterns of Distribution

Rye is one of the most widely grown small grains. It can be produced as far north or south as other cereals, but finds little use in tropical areas. The Americas are low producers of rye, yet the crop will grow and produce well under a wide range of conditions. Other higher income

crops are chosen in preference to rye except where rye has a particular advantage in being able to produce under very low fertility or other adverse conditions.

There is a tendency to grow rye for forage purposes in warmer locations and for grain in colder climates. Nuttonson (1958) stated that winter rye production reaches beyond the Arctic Circle, or within a short distance of the northern limit of spring barley.

In comparing rye and wheat production in the Americas, the ratio is more than 50:1 in favor of wheat, while in Europe the ratio is about 2:1. In Russia the acreages of the two crops are nearly evenly matched. One important reason rye is grown so extensively in Russia, is that the plants can grow at lower temperatures than wheat. Further, rye can withstand lower temperatures without snow cover and grow where moisture and soil fertility are low. The root system of rye is vigorous and weighs about half again more per acre than wheat, according to Nuttonson's (1958) report of Russian data.

Volin (1951) stated that rye acreages declined in Russia from 1925 to 1935. Wheat is given preference on black soil areas and rye on the non-black soils which are generally inferior. Volin indicated that rye predominates in the whole of northern and central European Russia as well as in the Baltic Republics and the former Polish territory, but is outranked, or almost entirely replaced by wheat in the more southern and eastern regions. Within Russian postwar boundaries, there were 60.8 million acres of rye for 1935 to 1939, but 73 million or more acres for 1947, 1948 or 1949. Yields were about 13 bushels per acre or closely similar to acre yields in the United States.

Uses

The domestic disappearance of rye for the ten-year period, 1944 to 1953 inclusive, was given in the United States Agricultural Statistics of 1954. The quantities used for seed were almost constant over this period. While there was wide variation in the use of rye for feed, the amount used for food purposes was also relatively constant and was slightly less than that used for feed.

The amount used for spirits and alcohol fluctuated rather widely, reflecting the need for industrial alcohol toward the end of World War II.

Moderate amounts of rye were exported but this was more than offset by total imports.

In Europe the rye grain is used largely for bread-making purposes. Undoubtedly there are numerous other uses, such as flat bread, porridge and alcoholic products.

Jasny (1940) indicated that heavy consumption of rye bread was cen-

tered in Germany, Austria, Scandinavia, central and northern Russia as well as in Russian-dominated Baltic states, Czechoslovakia and Poland. Mixture of wheat and rye flour for bread was increasing. The use of pure rye bread has tended to be confined to the poorer populations which may be related to the belief that rye bread staves off hunger pangs longer than other breads. This may be the result of lesser palatability of rye and the longer time required for digestion. In using rye for flour, it is usually diluted with wheat flour, in order to make a more palatable slice of bread. However, a few bakeries in the United States use only rye flour for making bread in areas where immigrant populations are high.

Rye is used to a limited extent in feeding various classes of livestock. Delwiche *et al.* (1940), gave several formulas for using rye as a concentrate in feeding dairy cattle, fattening cattle, swine, brood sows, and poultry. Below are given typical formulas for dairy mixtures and for pigs fed in dry lot.

Dairy Mixture to Be Fed with Mixed Grass and Legume Hay, and Corn Silage or Roots; About 17 Per Cent Protein

Ground rye	400	lbs.
Ground oats, barley, or corn	250	"
Wheat bran	200	"
High protein concentrates[1]	150	"
Salt, preferably iodized	10	"
Total	1,010	"

For Pigs in Dry-Lot

Ground rye	30.0	lbs.
Ground corn or barley	59.5	"
Linseed meal or soybean oil meal	5.0	"
Ground alfalfa hay	5.0	"
Salt	0.5	"

[1] High protein concentrates may be linseed meal, cotton-seed meal, gluten meal, soybean meal, or the equivalent amount of protein by way of some other protein concentrates.

It can be seen that about 40 per cent of the dairy mixture is composed of ground rye, while 30 per cent is used for the pig ration. Formulas were also given for poultry use. However, the amount of rye was only about 20 per cent in this case.

The rye crop is used quite widely for pasturage in the United States. To a lesser extent it is used for hay and cover cropping. Since rye is very winter-hardy, adapted types produce green feed during the winter in much of the southern half of the United States. Rye is used also in early fall and early spring pasturing in other sections of the country.

While there have been complaints about rye flavoring the milk from dairy cows, part of the trouble may be caused by distasteful weeds such as wild onions growing in the rye. There is no convincing proof that the rye pasture flavor is any more undesirable than that of other pasture plants. Furthermore, the pasture flavor of the milk may be reduced by removing the cows from the pasture two to four hours before milking.

GROWING, HARVESTING, AND STORING RYE

Culture

Culture of rye has been reviewed by Martin and Smith (1923), Leighty (1916), and Delwiche *et al.* (1940). These and other writers pointed out that rye will grow on good soils, but for economic reasons is sown on soils that are low in fertility and moisture holding capacity. Although rotation is desirable, rye can be grown for several years on the same fields without the benefit of rotation as is often done in Europe. Rye may follow corn in the rotation in the central states. Corn most often follows a hay crop that was first established by use of a spring grain crop. The rotation would then be rye, spring grain used as a companion crop, hay, and corn. Rye fits into numerous other rotations, but often is omitted intentionally in areas where it volunteers in the winter wheat crop. Sometimes rye is pastured in the fall and in the spring, then plowed under and followed by corn. Rye has been used occasionally as a companion crop for establishing grass and legume seedings that were spring seeded on frozen ground. Delwiche *et al.* (1940), listed several rotations for various soil types in Wisconsin. Corn, potatoes, or sugar beets might precede rye. The crop might be followed by spring grain seeded with grasses and legumes which can be used for hay or pasture for two or more years. Rye also might be substituted for wheat in rotations.

In Russia, Williams (1952) recommended that wheat and rye follow grass in a grass-arable rotation. Sugar beets or potatoes could follow rye. This was desirable because beets and potatoes did well where soil nitrogen was relatively low. A rotation of rye, sugar beets, and rye is followed in western Europe. There eelworm is enough of a problem to enforce rotation. Volin (1951) discussed rotations followed in cropping systems in Russia where rye makes up a considerable percentage of the acreage. He stated that Williams had recommended that grass-legume crops be used in a soil-improving system. The results were not immediately successful because of the shortage of grass seed. It must be kept in mind that, as pointed out by Nuttonson (1958), a great deal of Russian farmland receives low annual rainfall, and moisture conservation must be practiced. Therefore, the fallow system is part of their rotational plan.

Nutrient Requirements

Rye utilizes the major and minor elements in producing a crop. Nitrogen, phosphorus, and potassium are the major elements usually applied. Lime for the provision of calcium for soil acidity correction and nutrition is applied especially for the legume in the rotation. In many rye soils no fertilizer is applied at planting time, but instead the crop is topdressed with a nitrogenous fertilizer. This is especially true where rye is sown as a cover and grazing crop between cotton rows in the South. Nevertheless, Delwiche *et al.* (1940), and Albert (1951) recommended complete fertilizer for increased grain yields.

Delwiche *et al.* (1940) pointed out that applications of phosphate and potash could be made at seeding time using rates of 200 to 400 lbs. per acre. They indicated that nitrogen could be used in the fertilizer applied at seeding and that formulas in the neighborhood of 10 to 14 per cent N, 6 to 8 per cent P_2O_5, and 9 to 12 per cent K_2O were adequate. They also suggested that 20 to 60 lbs. of elemental nitrogen could be applied as top dressing in the spring after growth starts. For each 15 to 20 lbs. of nitrogen they expected an increase of 5 bushels of grain per acre. Albert (1951) stated that when soil phosphate and potash were low in availability, 500 lbs. of 12–4–8 or an equal amount of 10–10–10 may be applied at seeding time. He also indicated that 5 to 7 bushels or more of rye grain and 500 lbs. of straw would be produced per acre with each 20 lbs. of nitrogen used as top dressing. Widdifield (1953) in North Dakota suggested that 50 lbs. of phosphate and fertilizer such as 0–43–0 or its equivalent could be used for rye on fallow ground. On non-fallow ground he suggested the use of 70 lbs. per acre of a fertilizer such as 8–32–0.

Soil Management and Seedbed Preparation

Rye responds moderately well to carefully managed soil; but since it is sown on sandy soil or on soils of low fertility, soil preparation is usually kept to a minimum. When rye is sown on summer-fallowed land the crop will act as a competitor for weeds and check their growth according to Martin and Smith (1923). Where rye follows a corn crop that was ensiled, it is desirable to plow the land. However, rye land may be prepared by disking only. Rye is sometimes drilled into grain stubble without previous preparation. Drill rows are 7 or 8 inches apart.

Variety Choice

The choice of a variety depends somewhat on whether the crop is to be used as a cover crop, pasturage, or for grain. If the purpose is for grain production, the variety must be winter hardy enough to withstand

winter conditions in the area grown and should be of a type preferred by the cash market. Some buyers of rye grain prefer kernels of varying colors while others prefer rye that has a clear amber color resembling that of wheat. The germination of the rye seed should be tested before sowing because rye loses germination capacity more rapidly than do other small grains. Farmers generally increase seeding rates when rye has been stored more than a year. Seed may be treated with an organic volatile mercury compound if the seed is weathered or known to carry seed-borne diseases that are amenable to control by ordinary seed treatment practices.

Sowing the Crop

Rye should be sown in time to make considerable growth before winter sets in. Good crops are obtained if seed is sown in late August in Canada or the northern part of the United States. The date may be later depending upon the latitude and whether or not the crop is to be used for fall pasture. Nuttonson (1958) showed that rye was planted in early August at a north Finland location. Harvest was in September or 13 months later.

In South Dakota Hume *et al.* (1926) in an eight-year test found September 15 to be the optimum planting date. Champlin (1927) in Saskatchewan after a three year test concluded that the optimum planting date was September first. Rye may be sown somewhat later than winter wheat and will produce enough growth to live over winter.

It is preferable to sow rye with a drill at a rate of about six pecks per acre. Depth of seeding may vary from 1 to 3 inches. Champlin (1927) seeded rye with a single disk drill at a depth of 2 to 3 inches in grain stubble. He used the Dakold variety in his tests. In a seeding rate test where he planted 2 to 8 pecks per acre at one peck intervals, he obtained the following net yields in bushels per acre respectively: 28.5, 32.2, 32.7, 35.2, 35.2, 35.4, and 36.2. The highest net yield was obtained at the eight pecks per acre seeding rate but this probably was not significantly different from the five peck rate. When sowing between cotton rows in southern United States, the rate may be as low as 2 to 4 pecks per acre.

Harvesting

In areas where rye is widely grown, it matures earlier than other small grain crops. A large part of the crop is harvested by the use of a combine. However, there is still a large portion that is cut by a binder and later threshed by a stationary thresher. Rye tends to shatter and should be combined as soon as moisture is low enough for safe storage. It may be higher in moisture content if cut with a binder. In this case shocks should be made so as to protect grain from rains and dews.

Storing

Rye is stored in many types of buildings and under a wide variety of conditions. On the farm, most buildings are wood in construction and frequently are divided for livestock use and grain storage. Round metal bins and quonset huts may be used for farm storage in the north central region of the United States. Concrete bins and metal bins are used commercially. Shedd and Cotton (1949), as well as Phillips and Hansen (1954), noted that all types of bins should meet the following basic requirements: 1. retain quality of grain; 2. exclude forms of water; 3. protect against thieves, rodents, birds, poultry, insects, and objectionable odors; 4. provide for effective fumigation; 5. be safe from fire and wind; and, 6. have adequate head room for sampling.

Technical studies of grain concerning respiration, gas interchange, and insect and moisture relations have been undertaken with wheat, but infrequently with rye. Since the structure of the rye kernel is similar to that of wheat in many respects, it is assumed that storage conditions satisfactory for wheat would prove equally satisfactory for rye.

Since rye matures earlier in the summer, the moisture content more quickly reaches a safe storage level when compared to wheat or other grains. The first means of avoiding spoilage is to store rye at a satisfactory moisture level. This varies somewhat with geographical location. If harvested when moisture is near 13 per cent and stored under dry conditions free from insects, rye should remain free from storage trouble. Stored rye should be examined after binning in order to follow temperature changes. If heating is noted, the grain should be recleaned and moved to another bin. Forced ventilation can be used commercially.

Nuttonson (1958) presented a chart showing the moisture content of rye at harvest time in various parts of the Soviet Union. A high proportion of the rye is grown in areas where the moisture at harvest is above 15 per cent. If stored at such moistures in the United States, undoubtedly there would be considerable trouble. The outside temperatures in Russia very probably are low enough to prevent spoilage in the early fall and winter. A large portion of the rye grown in Europe is harvested under rather damp conditions which results in sprouting of the seed, as suggested by Hintzner and de Miranda (1954).

Walkden *et al.* (1954) listed the following precautionary measures to avoid grain storage troubles:

1. Store grain in a well constructed, isolated granary.
2. Store the grain in as dry a condition as possible.
3. Remove all old grain from bins and any grain and feed accumulations from other buildings on the farmstead to prevent a buildup of insect populations.

4. Apply residual spray to the ceilings, walls, and floors of the granary or crib and other buildings at least two weeks before feed grain is to be stored.
5. Fumigate all old grain which cannot be removed from the granary before new grain is binned.
6. Fumigate unprotected small grains within six weeks after harvest.
7. Inspect grain at frequent intervals to discover insect infestations or heating.
8. Fumigate the binned grain a second time if infestations develop.

CHEMICAL AND PHYSICAL CHARACTERISTICS

Chemical Analysis

Only a small amount of work has been done making strict comparisons between rye varieties except for plot yields. Instead, composite samples of rye have been examined for chemical and physical characteristics. Morrison (1956) gave the overall chemical compositions of rye grain, flour, and middlings as shown in Table 15. He also compared the chemical composition of wheat and barley. Protein and fat composition of rye, wheat, and barley grains were generally similar, ranging close to 13 per cent and 1.8 per cent, respectively. Fiber percentages of wheat and rye grain are essentially similar as was true of nitrogen-free extract and minerals. Rye was somewhat lower in total digestible nutrients than barley or wheat. Total digestible nutrients of rye flour and middlings were lower than that of the grain. The flour was lower than rye grain in protein, fat, fiber, and minerals. However, middlings had higher protein, fat, fiber, and mineral percentages but lower nitrogen-free extract than either the grain or flour.

TABLE 15

CHEMICAL COMPOSITION OF RYE GRAIN, FLOUR AND MIDDLINGS COMPARED WITH WHEAT AND BARLEY[1]

Product	Total Digestible Nutrients	Protein	Fat	Fiber	Nitrogen-free Extract	Minerals Total	Minerals Ca	Minerals P	Minerals K
					Per cent				
Rye grain	76.5	12.6	1.7	2.4	70.9	1.9	0.10	0.33	0.47
Rye flour	74.5	11.2	1.3	0.6	74.6	0.9	0.02	0.28	0.46
Rye middlings	72.0	16.6	3.4	5.2	61.2	3.8	0.06	0.63	0.63
Wheat: Ave. All types grain	80.0	13.2	1.9	2.6	69.9	1.9	0.04	0.39	0.42
Barley grain common—not including Pacific Coast States	77.7	12.7	1.9	5.4	66.6	2.8	0.06	0.40	0.49

[1] From Morrison (1956).

Schuette and Palmer (1938) analyzed rye germs and found that they contained 13.23 per cent ether extract; 39.76 per cent crude protein; 27.37

per cent carbohydrates; 6.82 per cent lignin; and 2.44 per cent crude fiber. Albuminoid nitrogen was the largest component of the protein. Sucrose, pentosans, starch, and raffinose in decreasing percentages made up the carbohydrate content. These workers stated that rye germ is a high protein, phosphorus-rich substance in which the lipoids predominate over the phytin forms of the latter.

Rohrlich and Rasmus (1956) compared the proteins of rye and wheat after manually separating small quantities of the germ, aleurone, and endosperm. In the rye aleurone (and pericarp) they found almost equal quantities of albumin, globulin, and prolamine. In contrast, wheat had a much higher proportion of albumin in the aleurone and a much lower proportion of prolamine. The rye was a tetraploid form, presumably Tetra Petkus. Paper chromatography was used in determining the amino acids present in the aleurones, germs and meal or flour from wheat and rye. They were able to identify 18 amino acids as follows:

Alanine	Histidine	Proline
Arginine	Leucine	Serine
Aspartic Acid	Lysine	Threonine
Cystine	Isoleucine	Tryptophan
Glutamic Acid	Methionine	Tryosine
Glycocoll	Phenylalanine	Valine

These workers did not find qualitative differences between the amino acids of germ and the aleurone. They noted, however, that the wheat endosperm was lower in arginine and lysine when compared to that of the rye endosperm.

Orr and Watt (1957) summarized the data available on 14 amino acids expressed in terms of amino acid content per gram of nitrogen present in whole grain and flours of different extractions as well as amino acid content for 100 grams of bread from light and medium rye flours. More amino acid content was found in bread from medium flour than bread made from light flour. Of the amino acids listed above, they did not present data for alanine, aspartic acid, glycocoll, and proline. Glutamic acid, leucine, valine, arginine, and phenylalanine were among those that had the highest percentages.

In studying higher molecular gums of cereals Preece and Hobkirk (1953) found that rye was rich in water soluble pentosans with very little if any contamination with beta glucosan. Pure pentosans were more readily obtained from rye than from other cereals. The major units of gums identified from rye were glucosan, xylan, araban, and galactan. These workers (1955) later separated rye and oat polysaccharides by electrophoresis. Rye had clear separation into two bands, while oats had

three bands. They were able to recognize the following sugar units in hydrolysates of rye: glucose, xylose, galactose, and arabinose.

Physical Properties

The physical properties of the rye grain are concerned with bushel weight, kernel weight, and other characteristics. Though the legal weight for rye is 56 lbs. per bushel, only plump rye of the diploid type frequently reaches this weight. Tetraploid rye is about two pounds less in bushel weight. The kernel weight of rye is about 26 mg. while the tetraploid forms are nearer 40 mg. per kernel. As already suggested, rye kernels vary a good deal in color and most of them tend to be "rough" in appearance because of wrinkled pericarp (see Fig. 24). Further, rye tends to sprout before harvest according to many European reports. Rye samples with ruptured pericarp above the embryo are frequently observed; this suggests incipient sprouting.

Ljung (1948) noted differences in germination of rye varieties immediately after harvest, one reaching 22.6 per cent while another had only 9.0 per cent after being placed under favorable germination conditions for 4 to 5 days.

IMPORTANT FUNCTIONAL CHARACTERISTICS

Flavor

On a world-wide basis the rye grain is used to a great extent in making bread, and to a lesser extent for feeds and distilled products. Of importance to the user is the flavor which means different things to different people. This is especially true for the taste of rye bread.

Rye "Glutens"

Johnson and Bailey (1925) studied the gluten and gas-retaining capacity of rye flour dough. They found that the rate of gas production in the dough was high, but that the gas-retaining capacity was low and was probably responsible for the dense compact loaves that are ordinarily baked from pure rye flour. Cunningham *et al.* (1955) extracted "glutens" from rye, wheat, barley, and oats by use of formic, oxalic, and citric acids. The formic acid gluten of rye absorbed 70.3 per cent water while that of wheat, barley, and oats absorbed 65.0, 55.2 and 50.2 per cent respectively. These workers thought that carbohydrate gums may have caused differences in water absorption rather than variations in the protein moiety. A judging panel thought that rye gluten was intermediate in elasticity and cohesiveness when compared to wheat gluten which was quite elastic and cohesive.

Palatability as Feed

In feeding rye, palatability is thought to be important. Many workers consider rye unpalatable, and it is probably this reason that prompted Delwiche *et al.* (1940) to suggest mixtures of rye in the grain portion of cattle rations. Wilson and Wright (1932) in South Dakota noted that cattle did not eat large quantities of rye when fed free choice. They further noted that the finish of the cattle lacked lustre. In their feeding experiments with hogs, daily gains with rye were greatly improved when it was mixed with corn or barley.

QUALITY TESTS

Bread Making

Strict quality tests for variety comparisons are relatively unavailable for rye. Hintzner and de Miranda (1954) studied the baking quality of eight varieties of diploid rye grown at six locations in the Netherlands in 1948. They tabulated their results for the field means of six varieties, and noted that the location where grown had a great influence on the baking quality. The differences among fields seemed to be greater than among varieties. Apparently the grain from the field identified as "F" had sprouted and therefore had greater alpha amylase activity and soluble substance in the bread. Field "E" had greater viscosity as measured by Brabender units and panimeter value which is a measure of the bread in recovering its original volume after being compressed. The variety listed as "I" had greater amylase activity which was reflected by reduced viscosity. Bread from rye of variety "II" had more compression resistance. In addition, these workers compared diploid and tetraploid rye flours for baking qualities. They photographed three loaves of tetraploid rye bread that appeared to be satisfactory for quality, and one loaf of diploid rye bread that showed a large air hole and excessive starch degradation. The latter was attributed to more sprouting in the diploid rye. They further noted low amylase activity of tetraploid rye which is in contrast to the report of Fifield and Reitz (1958) who found that the average amylase activity of Tetra Petkus was higher than that of the comparably grown diploid varieties Adams, Balbo, and von Rumker. The latter workers made baking tests and physical and chemical tests of the rye grain, and its flour. They provided test weights per bushel, kernel weights, diastatic activity, amylograph values for the flour as well as other comparisons as shown in Table 16. They blended rye flour 40 per cent with 60 per cent first clear wheat flour and made baking tests with this mixture. They found that Tetra Petkus flour made bread that was generally satisfactory and of about the same quality as the bread of diploid rye samples. Bread from Tetra

TABLE 16

CHEMICAL, MILLING AND BAKING RESULTS ON TETRA PETKUS AND OTHER VARIETIES OF RYE GROWN IN WISCONSIN AND PENNSYLVANIA IN THE YEARS 1954 AND 1955[1]

	Madison, Wis. 1954			Composite from Madison Racine, Ashland & Marshfield, Wis. 1955		Composite from Penna. State University & Landisville, Pa. 1955		
Kind of Test and Unit	Adams	Caribou	Tetra Petkus	Tetra Petkus	Adams	Tetra Petkus	Balbo	von Rumker
Protein[2]								
Grain, per cent	11.2	11.4	14.4	10.9	9.8	11.0	12.8	10.8
Flour, per cent	6.8	9.3	11.3	7.7	6.6	8.0	9.6	7.4
Weight per kernel, mg.	...	...	...	41.8	26.1	43.7	27.2	34.7
Flour ash,[2] per cent	.67	.44	.48	.58	.58	.63	.64	.65
Diastatic activity,[3] mg.	224	220	261	201.	217.	180.	165.	162.
Test wt. per bu.,[4] lbs.	56.0	56.9	52.1	52.5	52.1	54.5	56.2	55.5
Flour yield,[5] per cent	62.8	61.9	61.9	57.9	60.1	62.2	57.0	60.8
Amylograph (flour) values	...	...	...	167	292	340	850	565
Mixogram pattern	...	...	...	Md. weak	Weak	Weak	V. Weak	Weak
Bread[6]								
Blend of 40 per cent rye and 60 per cent 1st clear wheat flour								
Absorption, per cent	59.0	60.0	61.0	60.0	58.5	59.0	62.0	63.0
Loaf volume, ml.	662	687	678	659	645	651	656	694
Grain and texture, score	70 G	65 G	50 G	90	85	70 G	90 VG	95 VG

[1] Fifield and Reitz (1958).
[2] 14.0 per cent moisture basis.
[3] Mg. of maltose per 10 gm. of flour.
[4] Dockage free.
[5] Moisture free basis.
[6] Formula ingredients—flour, salt, yeast, shortening, and water.
Symbols Used: VG, very good; G good.

Petkus rye scored lower in grain and texture than bread from the diploid ryes and further, Tetra Petkus dough samples were sticky and handled with difficulty. Taste panels, as might be expected, did not agree as to flavor preference. In 1954, 12 of 15 tasters indicated that the flavor of Tetra Petkus bread was stronger than that of the three diploid ryes. In 1955, 9 persons of a 20-member team found the bread from Tetra Petkus stronger and more pleasing, while 5 preferred the flavor of the bread from the Adams variety, and 6 could find no flavor difference between the bread of the two types of rye.

Vitamins

Ihde and Schuette (1941) analyzed commercially-made rye flour for its content of the following B vitamins: thiamin, nicotine acid, riboflavin, and pantothenic acid. They reported detailed figures for whole rye, rye germ, and other milled products. Their results are given in Table 17.

TABLE 17

VITAMIN B VALUES FOR RYE AND SOME OF ITS PRODUCTS. AFTER IHDE AND SCHUETTE (1941).

Product	Individual B Vitamin Readings			
	Thiamin	Nicotinic Acid	Riboflavin	Pantothenic Acid
	μg./Gm.	μg./Gm.	μg./Gm.	μg./Gm.
Whole rye	2.4	12.9	1.5	10.4
Rye germ	9.3	27.0	4.46	13.9
Middlings from whole rye degermed	3.3	16.7	2.5	23.1
Middlings from degermed rye	3.3	17.7	2.0	23.1
Dark flour from whole rye	3.2	12.2	1.7	13.4
Dark flour from degermed rye	3.6	12.5	1.8	14.9
White rye flour from whole flour (not bleached)	1.5	7.1	0.76	7.1
White flour from whole rye (bleached)	1.6	7.3	0.69	7.25
White flour from degermed rye (bleached)	1.4	7.3	0.68	6.5

Three of the vitamins had their greatest concentration in the germ, while pantothenic acid reflected higher values for the outer layers of the kernel. Booher *et al.* (1942) summarized findings on vitamin A and B_1 values. They reported the lower percentage extraction flour from Germany to be lowest in vitamin content while it was higher as the greater per cent of the grain was milled. Schultz *et al.* (1942) found that rye varieties had different levels of B_1 vitamin but that these differences probably were not significant.

Nutrition

Sure (1954) fed the Wistar strain of albino rats whole wheat and whole rye flours that were adjusted to protein levels of 9, 8, and 5 per cent.

The rye was grown in Arkansas and the wheat was supplied by General Mills. At all levels of protein the animals made considerably more growth and showed greater protein efficiency on whole rye flour than on whole wheat flour. Increased growth in favor of rye was 39.4, 63.5, and 177.4 per cent for 9, 8, and 5 per cent protein levels, although gains were reduced at the lowest protein percentage. Ihde and Schuette (1941) found that rye flour contained two-thirds as much of the total vitamin B as the whole grain and that it was definitely a richer source of the B complex than whole wheat. Even refining the rye flour failed to reduce the vitamins to as low a level as that of wheat flour.

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N. W. Kramer

Sorghum

INTRODUCTION

Sorghum was harvested for grain on an average of about 9,785,000 acres in the 10-year period, 1948 to 1957. The average yield per acre was 21.4 bushels (1,198 lbs.), resulting in an average annual production of 209,233,000 bushels. As a cereal crop in the United States, sorghum is currently exceeded in production only by wheat and corn, and in total acreage by corn, wheat, oats, and barley.

Sorghum is the major feed grain grown in the Great Plains area stretching from the South Plains of Texas to South Dakota because it is better adapted to and more productive under the subhumid and semiarid conditions of that area than any other grain crop. Sorghum produces grain more reliably than any other crop under the hazardous farming conditions of the subhumid and semiarid areas. Its performance under adverse conditions gives it a value above the cash value of the grain and helps to maintain a more stable agricultural system. The residue from a sorghum crop that was a failure from the standpoint of grain production has often prevented the loss of land by wind erosion.

Adaptation

Sorghum is well adapted to semiarid areas, but it can make good use of additional water and is grown extensively under irrigation in dry areas. The most favorable mean temperature for the growth of sorghum is about 80° F. The sorghum plant withstands extreme heat better than most other crops, but extremely high temperatures during the fruiting period, in combination with low moisture levels, may reduce the grain yield.

Certain structures and processes of the plant adapt it particularly well to hot and dry conditions. The plants of some types of sorghum become partially dormant, and, as farmers say, "wait for rain" during dry, hot periods but resume growth when more water becomes available; this characteristic is particularly valuable in areas where short drouth periods may be expected to be followed by periods of rain. Types of sorghum which do not exhibit this characteristic are especially useful where rainfall is definitely seasonal and the cessation of rainfall indicates the be-

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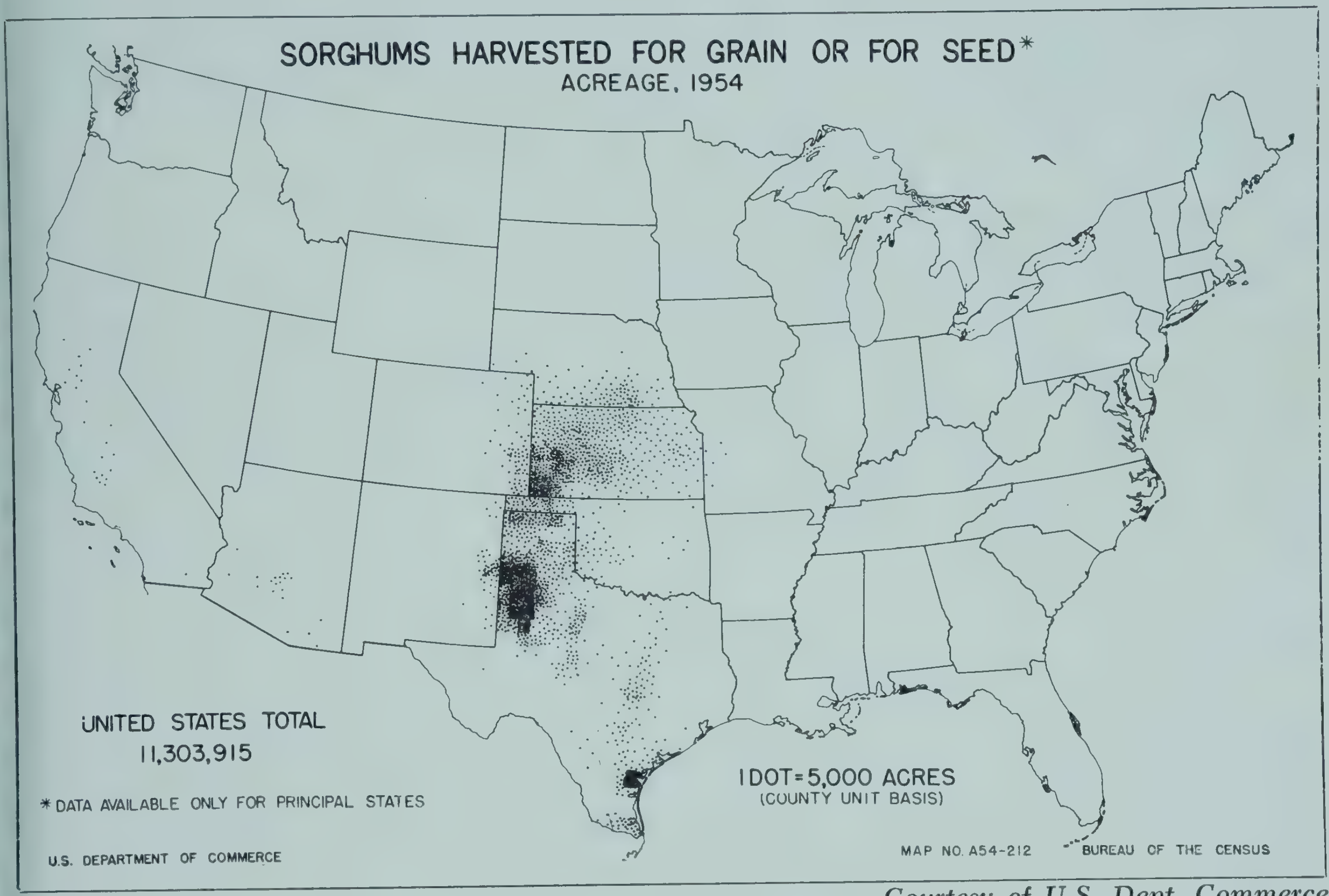
ginning of a long dry period; under such conditions these "non-stop" types produce grain while types that tend to become dormant might produce no grain. Compared to corn, sorghum has more secondary roots, a smaller leaf area, and a markedly more xerophytic type of leaf structure (Miller 1916). Sorghum leaves inroll as they wilt and have a waxy cuticle that apparently retards transpiration.



Courtesy of U.S. Dept. Commerce

FIG. 25. SORGHUMS HARVESTED FOR GRAIN OR FOR SEED

Sorghum is grown on all types of soil; in the area in which it is most widely grown the ability of a soil to provide water is usually its most important characteristic. Under good climatic conditions sorghum does best on deep fertile soils. In dry areas sorghum often does best on sandy soils because of their water infiltration and retention characteristics. Sorghum varieties differ in their reactions to salt concentrations, soil air and moisture, and other soil properties.

Origin and History

Sorghum is thought to have originated in Africa. That it was grown in ancient times is shown by a carving depicting sorghum found in an Assyrian ruin dating from about 700 B.C. (Ball 1910).

The first seed of any kind of grain sorghum brought to the Western Hemisphere probably came in slave ships from Africa. One variety

called "chicken corn" escaped from cultivation and is a weed in some of the Southern States; another, called "guinea corn" was once rather widely distributed but has now practically disappeared from cultivation. White Durra and Brown Durra were introduced from Egypt to California in 1874. White Kafir and Red Kafir were introduced from Natal, South Africa, about 1876. Milo was introduced from Colombia about 1879, but there is no information as to how the variety reached Colombia. Shallu was introduced from India about 1890, Pink Kafir from South Africa about 1904, and Feterita and Hegari from the Anglo-Egyptian Sundan in 1906 and 1908 (Vinall *et al.* 1936).

Recent Changes in the Crop

Grain sorghums have been greatly changed in the past twenty years in respect to the types and varieties grown. The tall types that were grown through the 1930's have been completely replaced by shorter "double dwarf" or "combine" types, with the result that the earlier bottleneck of hand heading has been completely eliminated by combine harvesting. In the same period earlier varieties with a consequently lower total water requirement were developed; these resulted in greater sureness of production in the older sorghum growing areas and in the extension of production into drier areas and into areas with shorter growing seasons. Sorghum hybrids, which first became available in 1955, made it possible to increase yields 20 to 40 per cent and further increased the acreage of the crop by making it more profitable to producers. Improvement in hybrid quality and yield is continuing as a result of the work of experiment stations throughout the Southwest.

The acreage of sorghum has also been increased by some other factors. The crop so far has been relatively free of serious disease and insect pests. The earlier varieties have proved to be particularly well suited as a late-planted crop where wheat or other crops have been abandoned or lost to weather hazards. The occurrence of drouth periods that have reduced yields of corn more than those of sorghum have resulted in the replacement of considerable corn acreage by sorghum in the western part of the Corn Belt, particularly in the areas where annual precipitation is less than 30 inches.

In the very near future there will be some additional changes in the crop. Sorghums with yellow endosperm like yellow corn are being developed; this improvement will for the first time give sorghum grain vitamin A and xanthophyll and will put it in a better competitive position as a feed grain. A much stiffer stalk is being introduced to obtain greater resistance to lodging, and work is underway on improvements in seed size, threshability, and grain composition and quality (Kramer 1958).

BOTANY

Sorghum belongs to the family **Graminae,** tribe Andropogonae. All the annual sorghums have 10 pairs of chromosomes and belong to one species, *Sorghum vulgare,* which includes such diverse types as grain sorghums, sudangrass, broomcorn, and tall sorghums that may be grown for forage, silage, or syrup.

Sorghum is a coarse grass that may grow from two to more than 15 feet in height; the height of the widely cultivated grain sorghum varieties is usually between 2 and 5 feet. The stems are similar to those of corn; they may be fairly fine in grass sorghums or more than an inch in diameter in some grain and forage types. Some varieties of grain sorghum have juicy stalks and leaf midribs while others are dry and pithy. The leaves are smooth and have a waxy surface; the leaf structure is such that water loss is reduced to a low figure. The inflorescence is a loose to dense panicle that may bear as many as 2,000 seeds. The seed of different varieties varies greatly in size, pigmentation and other characteristics. Although all grain sorghums are annuals, they can survive as perennials where temperatures are mild.

DISTRIBUTION OF PRODUCTION

Sorghum is the chief food grain in much of Africa and parts of India, Pakistan, China, and Manchuria. Sorghum is the world's third most important food grain, being exceeded in utilization for food by only wheat and rice.

Statistics on the world production of sorghum are incomplete, but the total area of sorghum grown for grain is thought to be more than 80 million acres (Martin and Leonard 1949).

Sorghum is grown on all the continents below latitudes of 45° and on many of the islands of the East and West Indies. It is an important cereal crop in much of Africa and parts of India, Pakistan, China, Manchuria, and the United States. It is also grown to some extent in nearly all the countries in the southern half of Europe and Asia, and in Central America, South America, and Australia.

Most of the sorghum in the United States is grown in the Great Plains area stretching from Texas and New Mexico on the south to Colorado and South Dakota on the north, but considerable acreages are also grown in the western part of the Corn Belt and in the hot irrigated areas of the Southwest, with lesser amounts in the South Central and South Atlantic states. Statistics on sorghum acreage and production are reported for 23 states (Table 18).

The leading state in sorghum production is Texas, with an average of

Table 18

GRAIN SORGHUM ACREAGE AND PRODUCTION BY STATES[1]

State	Acreage 1946–1957 1,000 Acres	Acreage 1956–1957 1,000 Acres	Production 1946–1957 1,000 Bu.	Production 1956–1957 1,000 Bu.
Texas	4,665	6,052	106,041	181,148
Kansas	2,241	3,886	39,358	76,760
Oklahoma	708	704	9,983	10,688
Nebraska	426	1,436	10,993	4,489
Colorado	292	435	3,808	7,636
New Mexico	276	324	4,419	5,988
California	127	210	5,960	11,249
Missouri	100	388	1,469	8,550
Arizona	73	104	3,363	5,046
South Dakota	58	170	1,158	4,306
North Carolina	44	90	1,188	2,380
Arkansas	37	118	825	2,962
Iowa	34	194	1,469	8,550
Alabama	30	38	543	693
South Carolina	7	11	133	208
Indiana	4	14	142	620
Louisiana	4	6	82	145
Tennessee	[2]	58	[2]	1,506
Georgia	[2]	40	[2]	810
Mississippi	[2]	28	[2]	762
Kentucky	[2]	23	[2]	852
Illinois	[2]	14	[2]	615
Virginia	[2]	10	[2]	302
U. S. Total	9,164	14,408	193,998	384,091

[1] From Anon. (1957).
[2] No statistics.

nearly 51 per cent of the U. S. grain sorghum production in the twelve-year period from 1946 to 1957. Sorghum is the leading grain crop in Texas, and some kind of sorghum is planted on approximately one-third of the total cultivated acreage of the state. In Kansas and Oklahoma, the second- and third-ranking states in sorghum acreage, wheat is the only cereal that exceeds sorghum in acreage. In Nebraska and Colorado, ranked fourth and fifth in acreage of sorghum, the crop is fourth in acreage among the cereals, but in New Mexico, the sixth state in acreage, sorghum is the leading grain crop.

That the sorghum acreage is concentrated in the Great Plains area is shown by the fact that, in the twelve years ending in 1957, two states, Texas and Kansas, harvested 75 per cent of the total acreage of sorghum for grain. Those two states, with the addition of the neighboring Plains states of Oklahoma, Colorado, Nebraska, and New Mexico, harvested 93.9 per cent of the grain sorghum acreage, leaving only 6.1 per cent of the national grain sorghum acreage divided among the other twelve states for which statistics are reported for the 1946–1957 period.

In recent years there has been a great increase in interest in sorghum

in other parts of the U. S. This interest has been expressed in increased acreages, but the total acreage outside the Sorghum Belt remains small. The North Central states, excluding Kansas and Nebraska, harvested about four per cent of the national acreage in 1956 and 1957; much of the increase in this area was due to drouth conditions and to government agricultural programs. The Southwestern and South Central states, excluding Texas and Oklahoma, harvested about three per cent of the national acreage in 1956–1957; the acreage in this area has been influenced by the feed requirements of an increasing livestock population and by a trend to the planting of sorghum after winter crops when the land cannot be prepared for planting early enough to seed corn near the optimum planting date.

FLUCTUATIONS IN PRODUCTION

The acreage of sorghum planted varies greatly from year to year. It is affected in most of the area by weather conditions at planting time and by the acreage and condition of other crops grown in the Sorghum Belt. The acreage of sorghum is inversely related to that of cotton and wheat where these crops are grown in the same area as sorghum. On the western fringe of the Corn Belt, sorghum and corn are interchangeable crops; a succession of dry years may result in considerable shifting of acreage from corn to sorghum, while a series of years favorable for corn will reduce the sorghum acreage.

The acreage of grain sorghum began an upward trend in the 1940's when combine varieties became available. The shortage of farm labor, the development of the small combine, and the war-time demand for grain all contributed to the increase. Government agricultural policies that restricted the acreages of wheat, cotton, and corn in varying amounts also affected sorghum acreages. In individual years the sorghum acreage may change considerably because of weather conditions at planting or because of factors affecting the acreage of other crops, such as winter-killing or abandonment of wheat.

Much of the large increase in sorghum production in 1956 and 1957 can be attributed to a swing from other crops to sorghum because of a succession of drouth years and because of the effect of government agricultural programs on cotton, wheat, and corn acreage; and to the availability of the new sorghum hybrids. The 1957 sorghum crop set new records for acreage harvested, yield per acre, and grain production.

GROWING THE CROP

Cultural practices for sorghum are generally similar to those used for other row crops such as corn and cotton. The particular procedures and

implements used vary considerably, depending upon the soil, climate, preceding crop, the equipment available, and the usual practices of the particular area.

Rotation

Grain sorghum can follow almost any other crop, but in most of the sorghum-growing area production hazards and limited moisture restrict the number of crops that can be grown and their arrangement into crop sequences. Grain sorghum is often grown continuously or is alternated with other crops such as forage sorghum, sudangrass, broomcorn, corn, or cotton. In some of the irrigated areas in southern California and Arizona, sorghum may be the summer crop in a double-cropping system, with wheat or barley being grown in the cool season. In a few areas with moderate rainfall, a rotation of sorghum, spring barley or oats, and winter wheat is used. In some areas where both sorghum and wheat are grown, a three-year rotation of sorghum-fallow-wheat is used, providing a fallow period of 9 to 11 months for the accumulation of rainfall before the planting of each crop; this rotation is particularly adapted to use in narrow strips for the control of wind erosion because some of the land is always in a growing crop and the unplanted strips are not fallowed long enough for all the residue to disintegrate. In the irrigated area of the South Plains of Texas, a rotation of sorghum, soybeans, and cotton is gaining in favor. In the Corn Belt and in most of the South, sorghum replaces corn in the cropping sequence.

Sorghum sometimes depresses the yields of succeeding crops. This is thought to be due primarily to the greater depletion of soil moisture by sorghum and to the fact that sorghum roots usually remain alive until the plant is killed by frost. Sorghum roots, a high-carbon residue, do not decay appreciably until the next spring, sometimes causing a serious deficiency of available nitrates in the early part of the following season. Early tillage and applications of nitrogen fertilizer tend to reduce this effect of sorghum.

Preparation of Land

Preparation of land for sorghum usually begins as soon as possible after the harvest of the preceding crop. In most sorghum producing areas, the saving of soil moisture and the storage of hoped-for precipitation are among the most important factors concerned in land preparation, although loosening of compacted soil and the preparation of a seedbed are also important. Soil preparation usually consists of procedures to kill weeds and other vegetation, to loosen the soil to permit more rapid infiltration of precipitation or irrigation water, to roughen or ridge the

soil to catch blowing snow and reduce wind erosion, and to prepare the land for the planting operation. The common methods of land preparation are listing, subsurface tillage, plowing with either disc or moldboard plows, discing, and chiseling, or combinations of these methods. On some of the medium- to light-textured soils where the lister planter is used, the crop may be grown without any land preparation with very little reduction in yield.

Planting

Sorghum is usually planted in cultivated rows 36 to 44 inches apart, but considerable acreage is planted in narrower rows 20, 24, 28, or 32 inches apart or in paired rows with alternate 14- and 26-inch row spacings.

Courtesy Deere and Co.

FIG. 26. PLANTING SORGHUM AND APPLYING FERTILIZER WITH A 4-ROW LISTER PLANTER

Some sorghum is planted with a grain drill but most sorghum in dry areas is planted with the lister planter or with similar equipment which pushes away the dry surface soil so that the seed can be planted in moist soil without covering it too deep. With this equipment the seed is usually planted in the bottom of a furrow. In more humid areas sorghum is planted with surface planters that leave the soil level after planting. In a few areas where drainage is a problem or where early irrigation is needed, sorghum is planted on the top of lister beds. The optimum depth

of planting is about two inches, but deeper covering of the seed is often practiced in hot dry conditions.

The amount of seed to be planted per acre depends upon many factors: the prospective grain yield; seed size; seed viability; and conditions of soil and weather that may affect the percentage of emergence. Because of all the variables involved, it is impossible to make definite recommendations of rates of seeding. A good rule-of-thumb for average conditions is to plant about one and one-half pounds of seed for each 1,000 lbs. of grain yield expected. The application of this rule results in recommendations of as low as 1 to 2 lbs. per acre for some dry land conditions and as high as 10 lbs. per acre for favorable conditions, all of which are within the range of seeding rates used. Stands of sorghum can deviate considerably from optimum plant populations with relatively little effect on grain yields (Kramer 1957).

The minimum temperature for germination of sorghum seeds varies from 45° to 50° F. Germination and early growth is slow at soil temperatures below 60° F., so the planting dates for sorghum, because of temperature requirements, are necessarily a little later than those for corn and about the same as those for cotton. An equally important consideration where the growing season is long is that of having the plant grow in the most favorable part of the year in respect to temperatures and precipitation. For example, in all of Texas below the High Plains, planting is done as early as possible so that the crop will be growing in the early part of the summer when temperatures are lower and the probability of getting rains is greater; the latter part of the summer is hotter and drier and is much less favorable for sorghum production. In the northern part of the Sorghum Belt and at higher elevations, sorghum must be planted as early as possible because the whole season is needed for growing the crop. In the South Plains of Texas the optimum planting period is June 10 to 25, later than that of the northern areas; this date of planting results in the plants being small and having a low water use during the hottest and driest part of the summer in July and early August, and the period of highest water use by the plant is then reached in late August and early September when temperatures are lower and the probability of rainfall has increased.

Fertilizer

Sorghum uses relatively large amounts of the common fertilizer elements for high yields (Table 19). In much of the sorghum area, however, the crop is grown on dryland and yields are not high enough to be limited by fertilizer elements, so the use of fertilizer on sorghum is

TABLE 19

FERTILIZER ELEMENTS IN SORGHUM PLANT PARTS AT A YIELD LEVEL OF 100 BUSHELS PER ACRE[1]

Part of Plant	Production Lbs.	Nitrogen Lbs.	Phosphoric Acid Lbs.	Potash Lbs.
Grain	5,600	100	32	17
Leaves	1,770	15	5	9
Stems	4,980	10	4	14
Roots	2,920	9	10	5
Total above ground	12,350	125	41	40

[1] Quinby *et al.* 1958.

limited for the most part to the areas with higher rainfall and to irrigated areas.

If fertilizer is applied, it should be available in adequate quantities when it is needed by the plant; the time of application may be very important when fertilizers are side-dressed. The uptake of nitrogen by sorghum is very high during two periods, the period of rapid vegetative growth preceding heading and during the period of grain development. Phosphorus accumulation is highest during the early part of the period of grain formation, and potassium uptake is greatest during the period of rapid vegetative growth preceding heading (Wagner *et al.* 1913).

Irrigation

Although sorghum is a drouth-tolerant crop, it gives a good return from supplemental irrigation in most areas. The amount of water used by the plant is not a fixed value; it is affected by temperature, humidity, wind movement, soil moisture tension, and the duration of growth of the variety.

The most effective use of water is obtained when the crop is provided with adequate water for continuous vigorous growth throughout the season. In average conditions in the southern part of the Sorghum Belt the total consumptive use of water is usually 21 to 23 inches for a 100-bushel grain crop. Whenever the crop is in severe moisture stress, that is, if the available moisture in the top two feet of soil is reduced below 25 per cent of the total available storage capacity, potential yields are reduced.

Water use is low during the early growth of the sorghum plant, usually averaging 0.05 to 0.10 inch per day for the first 2 to 4 weeks. Peak use usually occurs during the late boot and early heading stage and may reach 0.33 inch per day. The water use usually averages about 0.25 inch per day from the boot through the dough stage (Swanson and Thaxton 1957). (The figures given above apply to stands of 80 to 120 thousand plants per acre with available soil moisture above 25 per cent.)

When pre-planting rainfall is insufficient to bring the soil profile to field capacity to depths of 5 to 6 feet, a pre-planting irrigation is usually made. If the soil is wet to such depths the later irrigations are then based on the moisture content of the top two feet of soil. Usually the first irrigation is made 30 to 40 days after planting unless rainfall has occurred, and subsequent irrigations are made as necessary to maintain available water in the top two feet above a minimum of 25 to 50 per cent. The frequency of application will depend on the water-holding capacity of the soil and factors that affect the rate of water use.

Cultivation

Sorghum is usually cultivated as are other row crops. Cultivation is practiced primarily for weed control. If the crop is planted on land free of growing weeds, cultivation is required only as new weeds grow. Early cultivations are often made with a harrow, rotary hoe, or knife sled; later cultivations are made with conventional row cultivators. Narrow-row plantings are often cultivated entirely with a harrow or rotary hoe.

Sorghum roots grow near the surface, so cultivation must be relatively shallow because destruction of roots at any time is detrimental to the crop.

Weeds in sorghum can be controlled with any of several chemical herbicides, but caution must be exercised so that neither the sorghum crop nor other crops nearby are damaged by the chemical.

Insects and Diseases

Sorghum is attacked by a large number of insects and diseases, but they seldom cause general losses, although some may be severe in local areas.

The most destructive insect pests are the chinch bug, sorghum midge, corn-leaf aphid, corn earworm, and sorghum webworm. The chinch bug is a sucking insect that often moves to sorghum from maturing small grain fields; a number of varieties are relatively resistant to this insect. The sorghum midge is a problem in the southern states; the larvae hatch within the glumes and prevent seed development. Aphids occasionally cause some damage, but most other insects attacking sorghum cause only minor or local damage.

The most important diseases of sorghum can be grouped into seed and seedling diseases, leaf diseases, smuts, and root and stalk rots. Species of at least seven genera of fungi may attack seeds and seedlings; damage from this group can be greatly reduced by seed treatment with an effective fungicide and by planting when conditions are favorable for rapid seedling emergence. Leaf diseases, including at least three bacterial and eight fungal diseases, are most common in humid areas; control measures

are the use of resistant varieties and sanitation. Sorghum is affected by three smuts, two kernel smuts that can be controlled by seed treatment and head smut which is soil-borne and can be controlled only by the use of resistant varieties. The most serious root and stalk rots are milo disease and charcoal rot. Periconia root rot or milo disease is controlled by planting immune varieties. Charcoal rot is often a problem when the crop is subjected to extreme heat or drouth during the fruiting period; the disease causes disintegration of the pith and vascular structures in the lower part of the stalk, followed by premature drying of the plant and lodging. No complete control for charcoal rot is known, but the development of resistant varieties offers the best hope for control. Several other stalk rots are of lesser importance. (Quinby *et al.* 1958.)

Harvesting and Storage

Grain sorghum is usually harvested from standing stalks with a combine. The grain is physiologically mature when the greenest seeds drop to 35 per cent moisture, but it should not be harvested until the grain has dried to 13 per cent or less moisture unless the grain is to be dried artificially.

In the threshing operation the combine should be adjusted so that all the grain is threshed and separated from the stalks, a minimum amount of grain is cracked, and as little trash as possible is left in the grain.

Courtesy Allis-Chalmers Mfg. Co.

FIG. 27. HARVESTING COMBINE GRAIN SORGHUM WITH A 4-ROW SELF-PROPELLED COMBINE

Varieties differ in their suitability for harvesting from green plants before a killing freeze. Some varieties have a genetically-conditioned head-drying character that results in the rapid drying of the grain and head, while others tend to keep the grain at moisture levels too high for harvest until the plants are killed by frost.

Chemicals can be used to kill sorghum head tissues and speed drying, thus permitting earlier harvest, but the use of these harvest-aid chemicals must be limited to fields for seed production until they are cleared for use on food and feed grains.

Most of the sorghum grain is taken directly from the combine to country and terminal elevators, but in some areas a part of the crop is stored on farms.

In the more humid areas, much of the grain must be dried before it can be stored safely. At elevators most drying is done with heated air in relatively high-capacity driers, but sorghum can be dried with unheated air quite satisfactorily. For drying with unheated air the recommended depths of grain of different moisture contents, the air flow per bushel, and the periodicity of aeration will vary with local temperature and humidity values.

A tight structure is necessary to protect stored grain from weather, birds, rodents, and insects. Bins and storage areas should be cleaned and sprayed with a residual insecticide before grain is stored. The grain should be checked for temperature, moisture, and insect activity as often as necessary under the particular storage conditions.

Stored sorghum grain may be attacked by the common insects of stored grain such as the Angoumois grain moth, rice weevil, granary weevil, and others. The storage of clean dry grain in clean bins, along with aeration and fumigation as necessary, will control these insects.

STRUCTURE AND COMPOSITION OF GRAIN

The kernel of sorghum is similar in many respects to that of corn, but there are some important differences in structure and composition. One of the most striking differences is the smaller size and spherical shape of sorghum compared to the larger flattened corn kernels. In sorghum there is usually a much greater proportion of horny endosperm than in corn, and the cells and starch granules in the horny endosperm are smaller. The gluten matrix is thick and resistant to softening; it forms a continuous envelope around all starch granules within a given cell. The outer part of the horny endosperm, just beneath the aleurone layer, consists of a layer of small, densely proteinaceous cells called the dense peripheral endosperm layer. The floury endosperm in sorghum is

TABLE 20

FEEDSTUFF ANALYSIS OF SORGHUM AND CORN, PER CENT, DRY BASIS[1]

Component	Kafir	Corn
Ash	1.63	1.53
Fat	4.14	4.68
Protein	13.81	11.09
Fiber	2.72	1.92
Nitrogen-free extract	77.61	80.73

[1] Baird (1910).

TABLE 21

ELEMENTAL ANALYSIS OF THE ASH OF REDBINE-66 SORGHUM GRAIN GROWN IN MOORE COUNTY, TEXAS IN 1951, PER CENT OF GRAIN AS RECEIVED[1]

Element	Per cent[2]
Phosphorus	0.4
Potassium	0.3
Magnesium	0.2
Calcium	0.02
Iron	0.02
Manganese	0.02
Zinc	0.008
Silicon	0.004
Boron	0.001
Lead	0.001
Aluminum	0.0004
Molybdenum	0.0001
Copper	0.00008
Nickel	0.00008
Sodium	0.00008
Chromium	0.00004
Tin	0.00004
Titanium	0.00004

[1] From McNeill (1952).
[2] By semi-quantitative spectrographic analysis.

TABLE 22

CHARACTERISTICS OF THE FAT OF SORGHUM AND CORN[1]

Measurement	Values	
	Kafir	Corn
Specific gravity	0.94	0.924
Melting point	111.6° F.	66.2° F.
Iodine number	109.7	146
Saponification number	249.1	190
Reichert-Meissel number	6.10	7.05
Acetyl number	42.2	8.3

[1] From Baird (1910).

generally similar in physical characteristics to that of corn (Watson and Hirata 1955).

The chemical composition of grain sorghum is similar to that of corn. Generally, sorghum has more protein than corn, less fat, about the same amount and proportion of carbohydrate components, more tannin and

TABLE 23

COMPARISON OF THE VITAMIN CONTENT OF SORGHUM AND CORN, MICROGRAMS PER GRAM, DRY BASIS[1]

Vitamin	Yellow Corn	Milo
Riboflavin	0.93	1.11
Nicotinic acid	25.9	51.4
Pantothenic acid	4.6	7.0
Biotin	0.092	0.30
Pyridoxine	6.9	6.4
Xanthophyll and carotenoid pigments	5 to 70	None

[1] From Anon. (1958).

TABLE 24

COMPARISON OF THE AMINO ACID COMPOSITION OF THE PROTEINS OF CORN AND SORGHUM, PER CENT OF THE PROTEIN FRACTION[1]

Amino Acid	Corn	Milo
Glutamic acid	22.4	21.9
Leucine	14.9	15.2
Isoleucine	6.4	5.9
Phenylalanine	5.3	5.1
Methionine	2.2	0.8
Valine	5.3	5.9
Threonine	3.2	2.5
Tryptophane	0.5	0.8
Lysine	3.2	2.5
Arginine	4.3	3.4
Histidine	3.2	2.5
Total protein in grain	9.4	11.9

[1] From Baumgarten *et al.* (1946).

wax, and, except for the new yellow endosperm varieties, no xanthophyll and carotenoid pigments. Table 20 presents representative analyses of corn and sorghum.

The mineral content of sorghum grain reflects to some extent the soil on which the crop was grown and the characteristics of the species. Typical analyses are presented in Table 21.

The individual organic components of sorghum grain correspond in a general way to those of corn, but they vary significantly in some characteristics. Some representative data are presented in Tables 22, 23, and 24.

UTILIZATION

The principal use of sorghum grain in the United States is for animal feeds, and this use usually accounts for more than 90 per cent of the sorghum grain produced. Sorghum grain is approximately equal to corn as a feed grain for most classes of livestock, although the differences in contents of protein, oil, and vitamin A should be considered. Sorghum

may be used directly as a feed grain, or it may be processed by the mixed-feed industry into commercial feeds.

The industrial utilization of sorghum grain is a relatively recent development, although the industrial potential has long been recognized. Sorghum is now used in the wet-milling industry, in dry-milling, and in the fermentation industries. The primary product of wet-milling is starch and its derivatives, with an edible oil and gluten feed as the principal by-products. The starch is used in food products, adhesives, and sizings. The dry-milling process produces a low-protein flour and a feed by-product. The flour can be substituted for pure starch in many uses; it is currently used as an adhesive in the manufacture of gypsum wallboard and as an ingredient of oil-well drilling muds. Fermentation industries using some sorghum are the beverage distillers, brewers, and manufacturers of industrial alcohols (Martin and MacMasters 1951).

The only use of sorghum as a human food in the United States is in the form of products containing manufactured sorghum starch or its derivatives. In large parts of Asia and Africa, however, it is the most important food grain and makes up a large part of the human diet, with sorghum in some form being eaten at each meal (Karper and Quinby 1947). The use of sorghum for food could be greatly expanded in much of the world if the need arose, but for most areas outside those where it is now used as food it would be necessary to improve the grain quality of present varieties to make the grain more acceptable as food. Pop-sorghum, a sorghum that pops like popcorn but with a lower expansion ratio, offers some possibilities for food use as a confection or as a milled product prepared from the popped grain.

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H. M. Beachell

Rice

INTRODUCTION

Rice, one of the oldest and most important food crops, is the staple food of over half the world's population. World rice acreage exceeded 250,000,000 acres during the five-year period, 1951 to 1955. Annual world production of rough rice for the same period approximated 386 billion pounds.

Over 92 per cent of the world rice crop is produced in Asia and adjacent island areas of dense population. An even higher percentage is consumed in these same countries. In spite of this intense culture, most Asiatic countries are deficient in rice. Only Burma, Thailand and Indochina have an exportable surplus.

The United States produces slightly over one per cent of the total world rice crop but is the third largest rice-exporting country. The major rice-growing states are Arkansas, California, Louisiana, Mississippi and Texas, where production methods are highly mechanized. The machinery and methods used in growing and harvesting the crop are much the same as those used in producing other small grains, except that the fields are kept flooded throughout most of the growing season.

ORIGIN AND ANTIQUITY OF RICE

Rice probably originated somewhere in Southeast Asia, where it has been grown for many centuries. The earliest record of rice production in China dates back to about 2800 B.C. (Ghose *et al.* 1956) and in India back to 1000 years B.C. Later, rice culture spread westward to the Middle East, Africa and Europe. It was cultivated in the Euphrates Valley in 400 B.C., was mentioned by the Greek poet Sophocles in the Tragedies in 495 B.C. and was brought to Southern Europe in Mediaeval times by the Saracens. It has long been an important crop and food in Spain, Italy, and Portugal.

Rice culture in the United States began about 1685 in South Carolina and later spread to North Carolina, Georgia, Alabama, Mississippi and Florida (Jones 1936). As late as 1849, South Carolina, North Carolina and Georgia produced about 90 per cent of the United States rice crop.

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Courtesy of Louisiana Rice Expt. Sta.

FIG. 28. PLOWING LAND IN PREPARATION FOR SEEDING

Following the Civil War, rice production in the South Atlantic states decreased rapidly, followed by an increase in acreage along the lower Mississippi River in Louisiana. By 1900 rice production had spread to the coastal prairies of Louisiana and Texas and by 1905 was being grown in the Grand Prairie of southeastern Arkansas. By 1909 Louisiana and Texas were producing about 90 per cent of the United States rice crop. In 1912 the first commercial acreage of rice was grown in California.

Today, the five major rice-producing states are Texas, Louisiana, Arkansas, California and Mississippi, ranking in that order. Rice has also been grown commercially in Missouri, along the Mississippi River as far north as Palmyra. The average farm value of the United States rice crop for the five-year period 1951 to 1955 was about $266,000,000. It is the major cash crop in most of the counties and parishes where grown.

BOTANY OF THE RICE PLANT

Cultivated rice (*Oryza sativa*) belongs to the **Gramineae** or grass family and the tribe Oryzeae. Unlike the other cereal crops, rice is a semi-aquatic plant which thrives under flooded soil conditions. The chromosome number of *Oryza sativa* is 24 (2N). Among the wild species, both 24 and 48 chromosome types are reported.

Over 60 species of *Oryza* have been reported, but only 23 valid species are generally recognized, according to Chatterjee (1948). Most of the

Table 25

THE SPECIES OF ORYZA MOST COMMONLY RECOGNIZED, SHOWING THEIR CHROMOSOME NUMBER AND AREA OF THE WORLD WHERE FOUND[1]

Species of Oryza	Number of Chromosomes	Country of Origin
Oryza sativa (Cultivated rice)	24	Asia
Oryza glaberrima (Cultivated in Africa)	24	Africa
Oryza sativa var. fatua (spontanea)	24	Asia
Oryza alta	48	America
Oryza australiensis	24	Australia
Oryza brachyantha	24	Africa
Oryza breviligulata	24	Africa
Oryza coarctata	48	Asia
Oyrza cubensis—sometimes classed under *Oryza perennis*	24	America
Oryza eichingeri	48	Africa
Oryza grandiglumis	24	America
Oryza granulata	48	Asia
Oryza latifolia	48	America
Oryza meyeriana	24	Asia
Oryza minuta	48	Asia
Oryza officinalis	24	Asia
Oryza perennis	24	Asia, Africa, America
Oryza perrieri	. .	Madagascar
Oryza punctata	. .	Africa
Oryza ridleyi	48	Asia
Oryza schlecteri	. .	New Guinea
Oryza stapfii—sometimes classed under *Oryza sylvestris*	48	Africa
Oryza subulata	24	America
Oryza tisseranti	. .	Africa

[1] Formulated from information reported by Chatterjee (1948), Jones and Longley (1941), Ramiah and Rao (1953), and Sampath and Rao (1951).

wild species are found in Southeast Asia and Africa, but several species have been reported from the Western Hemisphere. A list of the more commonly recognized species of *Oryza* are shown in Table 25.

Cultivated rice does not cross freely with most wild species, except that *sativa* and *glaberrima* intercross freely (Ramiah and Rao 1953). A number of interspecific crosses have been reported by Ramiah and Ghose (1951) and Sampath and Rao (1951), but only limited information on the subject is available. Further cytogenetic studies of interspecific hybrids are needed before the relationship between cultivated rice and the various wild species can be established. Ramiah and Ghose (1951) reported that useful forms somewhat resistant to drought were obtained from a cross between *Oryza sativa* and *Oryza perennis.*

Ramiah and Rao (1953) state that over 8,000 botanically different varieties of rice are in existence in the world and that more than 4,000 varieties have been identified in India. Jones *et al.* (1953) report that over 8,000 varieties and selections were introduced into the United States for testing purposes during the 50-year period 1903 to 1952.

FIG. 29. LEVELLING LAND IN PREPARATION FOR RICE SEEDING

The varieties of *Oryza sativa* are usually divided into two subspecies, japonica and indica. Ghose *et al.* (1956) base classification on morphological differences, response to temperature and length of day. All of the japonica types have essentially the same grain and panicle type, according to Ramiah and Ghose (1951). Crosses between indica and japonica varieties show varying degrees of sterility. Jones and Longley (1941) concluded that japonica and indica varieties probably had a common origin many centuries ago and that gene mutations and chromosomal rearrangement are responsible for this incompatability. In the United States, the *japonica* and *indica* sub-species have been intercrossed and several important commercial varieties developed. A more complete description of the japonica and indica varieties will be undertaken in discussing the varieties grown in the United States.

The rice plant has a branched panicle type inflorescence. The spikelets are borne on the panicle branches, and each spikelet contains a single ovule and six anthers. The ovule when fertilized forms the rice grain, which is covered by loose outer hulls called the lemma and palea. The hulls remain intact when threshed and are removed as a first step in the milling operation. At the base of the lemma and palea are two outer glumes which remain attached to the grain when threshed and are usually greatly reduced in size.

The rice florets usually bloom after the panicles emerge from the leaf sheath. Blooming usually occurs at about the same time of day in each region where grown, but the exact time depends upon the daily fluctua-

tions in temperature and humidity. In the United States this occurs between the hours of 8:00 a.m. and 4:00 p.m., with most of the blooming occurring between 10:00 a.m. and 12:00 noon (Adair 1934 and Laude and Stansel 1927). Blooming is characterized by the opening of the lemma and palea. Simultaneous with the opening of the glumes is a rapid elongation of the styles bearing the anthers. Pollination takes place as the anthers dehisce, liberating the pollen grains which fall on the feathery stigma attached to the ovule. The glumes usually remain open about one hour.

Rice is a self-fertilized crop, but some natural crossing occurs. Natural crossing has been reported to vary from a fraction of 1 per cent to over 3 per cent (Beachell *et al.* 1938).

The rice grain is made up of the endosperm, the germ, and the bran or aleurone layers. The bran and germ are high in oil content. The composition of rough rice at 13.6 per cent moisture, according to Iso (1954) is 79.7 per cent starch, 7.43 per cent protein and 2.91 per cent fat. As will be discussed later, there is a wide variation in the physical and chemical makeup of the starch component of the endosperm of different varieties.

PRODUCTION AND TRADE STATISTICS

Rice production is widely distributed over the world in spite of the heavy concentration of production in southeast Asia. It is grown as far north as northern Japan (Hokkaido) and as far south as Argentina and Chile. A list of the more important rice-growing countries, their acreage, production, average yields, per capita production and consumption are shown in Table 26. The production figures are based on the five-year period 1951 to 1955, and consumption figures are based on the period 1934 to 1938.

It will be noted that average acre yields vary from over 4,500 pounds in Spain and Italy to less than 1,500 pounds in such countries as Indonesia, Burma, Pakistan, Thailand, India, Indochina and the Philippines. In general, the tropical countries produce low acre yields in comparison with temperate regions. The low yields produced in tropical countries are due largely to the intense culture practiced and the fact that much of the crop is dependent upon the monsoons for irrigation water, which may or may not be adequate. Drainage is also poor or nonexistent. The same lands are cropped year after year to rice, with little fertilizer being added. Frequently, lands not adapted for rice production are used in an effort to meet the ever-increasing needs for rice as food.

In Japan, comparatively high yields are produced (3,496 pounds per acre). This is the result of many years research in the development and use of adapted varieties and good cultural practices. Controlled irriga-

tion, soil-building crops and commercial fertilizers also contribute to the higher yields produced in Japan. The extremely high yields produced in Spain, Italy and Portugal are due to the use of soil-building rotation systems, the use of large amounts of commercial fertilizers and the dry climate resulting in less disease and insect problems.

FIG. 50. THE DISK TYPE LEVEE BUILDER IS WIDELY USED FOR CONSTRUCTING CONTOUR FIELD LEVEES ON THE LIGHTER SOILS FOUND IN THE SOUTHERN STATES

Average acre yields produced in the United States from 1899 through 1957 are shown by two- and five-year averages in Table 27. It will be noted that the average yield for the two-year period 1899 to 1900 was only 1,207 lbs. per acre, and by the period 1906 to 1910 it had increased to 1,642 lbs. Little change in average yields occurred until 1926 to 1930, when the five-year average increased to 2,000 lbs. per acre.

Again there was little change in average yields until the period 1951 to 1955, when the five-year average yield increased to 2523 lbs. The two-year average for the years 1956 and 1957 was 2,939 lbs., and the year 1957 was an all-time-high year, with an average yield of 3,068 lbs. per acre.

The increase in average yields occurring during the period 1926 to 1930 can be attributed to the development of tractors and improved implements that could be successfully operated under rice land conditions. Prior to this, mules and unadapted tractors had been used for power.

While a slight increase in average yield occurred from 1931 to 1940,

TABLE 26

WORLD RICE ACREAGES, PRODUCTION, AVERAGE YIELD, PRODUCTION AND CONSUMPTION IN LEADING RICE-PRODUCING COUNTRIES, 1951 TO 1955 AVERAGE

Country	Acreage 1,000 Acres	Production Million Lbs.	Average Acre Yield lbs. per Acre	Per Capita[1] Production Rough Rice Lbs.	Per Capita[2] Consumption Milled Rice Lbs.
Brazil[3]	5,487	7,367.1	1,343	120	66[4]
United States	2,085	5,282.9	2,534	31	5
Italy	428	1,954.2	4,566	40	23
Portugal	85	322.9	3,799	36	15
Spain	161	787.9	4,894	27	14
Burma	10,538	13,869.0	1,316	692	312
China[5]	55,789	125,287.0	2,246	211	191
India	75,791	84,900.0	1,120	219	176
Indochina[6]	8,810	9,111.7	1,034	526	307
Indonesia	16,144	23,939.8	1,483	285	189
Japan	7,555	26,409.5	3,496	291	294
Korea	2,548	6,658.0	2,613	218	200
Malaya	829	1,422.5	1,716	227	413
Pakistan	23,446	27,797.1	1,186	328	176
Philippines	6,548	6,876.4	1,050	303	212
Taiwan (Formosa)	1,908	4,708.0	2,468	570[7]	...
Thailand (Siam)	13,316	15,781.1	1,185	692	215
Egypt	518	1,691.7	3,266	72	37
Madagascar	1,849	2,431.4	1,315	540[7]	266
Other world countries	18,801	19,487.4	1,037	...	...
World total or average	252,636	386,085.6	1,528	141	90[8]

[1] Population data used in computing per capita production obtained from "1958 Yearbook, Encyclopaedia Brittanica."
[2] Per capita consumption figures are for the period 1934 to 1938 and from Efferson (1952) except where later figures were available.
[3] Data not otherwise attributed have been obtained from Agricultural Statistics, U. S. Dept. Agr.
[4] 1948 per capita consumption from Efferson (1952).
[5] Includes Manchuria and Tibet.
[6] Includes Cambodia, Laos and South Vietnam.
[7] Population data from Rand McNally-Cosmopolitan World Atlas, 1956.
[8] Based on 65 per cent of average rough rice yields.

there was a slight drop in yield from 1941 to 1950. The drop was only slight and occurred during a period of intense cropping of lands. Yields were maintained at the recent high level because of improved equipment, increased use of commercial fertilizers and improved varieties.

The increases in yields during the 1951 to 1955 period can be attributed to the increased use of commercial fertilizers, the use of herbicides for controlling weeds, improved cultural practices and better varieties. The 1956 to 1957 increases were brought about in part through acreage controls. Farmers no doubt cropped their better lands to rice and made fuller use of good farming practices.

Average yields produced in the different states vary considerably. California has consistently produced higher average yields than the other states, as shown in Table 28. The twelve-year average yield (1946 to 1957) for California was 3,306 lbs. per acre, as compared with yields of 2,647 lbs. for Mississippi, 2,449 lbs. for Texas, 2,399 lbs. for Arkansas and 2,070 lbs. for Louisiana. The higher yields produced in California are

due in part to soil and climate conditions and to varieties grown.

The lower yields produced in Louisiana are due to the fact that the lands used for rice production in Louisiana have been heavily cropped to rice for many years. From the early 1900's until recently, much of the rice land of Louisiana produced a rice crop every other year. The same is true of some of the lands in the eastern part of the Texas rice area.

FIG. 31. HYDRAULICALLY CONTROLLED STEEL BLADE LEVEE PUSHERS ARE USED FOR CONSTRUCTING CONTOUR FIELD LEVEES ON THE HEAVIER SOILS

Broadleaf weeds, annual grasses and sedges have heavily infested the fields and have been at least partly responsible for the low yields. Improved cultural practices such as land leveling, chemical weed control and water seeding have helped to raise the average yields on these lands.

Exports and Imports

Total world exports and imports of milled rice are shown in Table 29. It will be noted that only a small percentage of the total world rice crop moves in international trade. The 3-year average annual export and import totals for the period 1954 to 1956 amounted to slightly over 11 billion lbs. (Anon. 1955 and 1956). This amounts to less than five per cent of the total world crop of approximately 250 billion pounds of milled rice.

TABLE 27

AVERAGE RICE YIELDS IN POUNDS PER ACRE PRODUCED IN THE UNITED STATES DURING THE PERIOD 1899 TO 1957

Years	Average Yield in Lbs. per Acre
1899–1900	1,207
1901–1905	1,442
1906–1910	1,642
1911–1915	1,599
1916–1920	1,791
1921–1925	1,754
1926–1930	2,000
1931–1935	2,137
1936–1940	2,257
1941–1945	2,005
1946–1950	2,161
1951–1955	2,523
1956–1957	2,939

TABLE 28

ACREAGE AND AVERAGE YIELDS IN POUNDS PER ACRE PRODUCED IN THE VARIOUS RICE-GROWING STATES FOR THE PERIOD 1946 TO 1957

State	1946[1] to 1950	Period of Years 1951[1] to 1955	1956[3] to 1957	Average, 1946–1957[3]
Arkansas				
Acreage (1,000 acres)	359	498	364	418
Ave. yield (lbs. per acre)	2,200	2,370	2,966	2,399
Louisiana				
Acreage (1,000 acres)	594	602	428	573
Ave. yield (lbs. per acre)	1,768	2,210	2,491	2,070
Mississippi				
Acreage (1,000 acres)	6[4]	51	39	39
Ave. yield (lbs. per acre)	2,700[4]	2,515	2,923	2,647
Texas				
Acreage (1,000 acres)	483	562	381	499
Ave. yield (lbs. per acre)	2,077	2,650	2,874	2,449
California				
Acreage (1,000 acres)	255	372	263	305
Ave. yield (lbs. per acre)	3,216	3,185	3,835	3,306
United States				
Acreage (1,000 acres)	1,694	2,089	1,501	1,826
Ave. yield (lbs. per acre)	2,161	2,523	2,939	2,453

[1] Computed from "Agricultural Statistics" 1948 to 1956.
[2] Anon. (1958).
[3] Based on averages of individual years.
[4] Two-year average, 1949 and 1950.

Milled rice is usually calculated on the basis of 65 per cent of the rough rice weight.

The leading exporting countries are Burma, Thailand, and the United States. These countries usually account for well over 85 per cent of the export rice which moves in international trade. The United States, a

TABLE 29

LEADING RICE EXPORTING AND IMPORTING COUNTRIES FOR THE PERIODS 1946 TO 1950 AND 1954 TO 1956, EXPRESSED IN POUNDS OF MILLED RICE EQUIVALENT

Country	Average Annual Exports for the Years		Average Annual Imports for the Years	
	1946–1950 (1,000 Lbs.)	1954–1956 (1,000 Lbs.)	1946–1950 (1,000 Lbs.)	1954–1956 (1,000 Lbs.)
North America	1,032,068	1,480,510	704,811	568,737
Canada	1,026	2,315	42,747	67,794
Cuba	1	...	540,796	313,210
United States	962,170	1,462,691	3,170	18,259
Europe	198,998	787,574	515,259	1,452,676
Belgium and Luxembourg	603	26,535	47,354	120,326
France	1,001	3,845	78,731	163,190
Germany (Western)	...	4,504	88,967	224,582
Italy	177,639	526,084	748	864
Netherlands	11,906	59,193	52,742	199,183
Portugal	4,394	9,954	18,066	1,833
Spain	118	129,901	1,402	4
United Kingdom	3,120	...	83,431	193,749
Asia	4,660,562	8,151,086	5,261,322	8,457,443
Burma	2,147,120	3,647,436	...	...
Ceylon	1,812	12,432	810,906	939,668
China	2,814	731,667	501,306	71,667
Hong Kong	17,218	10,087	284,812	4,619,573
India	31,283	95,249	1,244,174	940,746
Indochina	244,605	400,775	83	...
Indonesia	1,458	28,304	453,363	844,118
Japan	7,909	338	388,872	2,526,675
Malaya	21,951	130,597	810,577	1,073,196
Pakistan	73,190	304,677	35,410	324,109
Philippines, Republic of	31,555	5,762	237,105	107,061
Taiwan	52,362	231,535	3,489	317
Thailand	1,919,197	2,657,527[1]	...	...
South America	553,657	353,960	91,356	58,244
Argentina	3,344	64,858	95	...
Bolivia	2	...	17,664	24,940
Brazil	321,092	76,374	...	1
British Guiana	51,496	98,253	...	...
Colombia	3,704	...	4,200	24,560
Ecuador	125,520	38,251	...	1
Africa	587,125	469,204	296,688	668,378
Egypt	548,238	339,268	63	102
French West Africa	798	...	75,083	203,195
Oceania	61,326	80,344	39,539	55,355
World Total	7,093,736	11,665,152	6,908,975	11,260,832

[1] Two-year average 1954 and 1955.

country producing slightly over one per cent of the world crop, accounts for roughly ten per cent of the world rice exports. The United States annually exports over 50 per cent of its total production.

The leading importing countries are Japan, Malaya, Ceylon, Indonesia, India, Hong Kong, Pakistan and Cuba. Cuba has been an important market for United States rice for many years. In recent years, Japan and other Asiatic countries have imported considerable United States rice.

THE CULTURE OF RICE

Climate

Rice can be successfully grown under a wide range of climatic conditions. Most of the world rice crop is grown between the Equator and 40°N. latitude, but rice culture extends from 45°N. to 40°S. latitude. The crop is commonly associated with tropical regions, but it is also widely grown in temperate regions. The many types of rice which have evolved through the centuries of extensive rice culture vary widely in their range of adaptability. Rice generally requires a minimum growing season of 4 to 5 months, during which the mean temperature averages 70°F. or above. The crop is grown at altitudes of from sea level to over 5,000 feet (Efferson 1952 and Ghose *et al.* 1956).

In tropical humid regions, rank-growing long-season varieties are commonly grown. In Malaya and parts of India varieties requiring a growing season of over 260 days are common. These tropical varieties tiller profusely and produce rank vegetative growth on soils that are annually cropped to rice. In low-lying flood plains deep-water rices, commonly called floating rices, are grown. These rices elongate as much as twelve inches a day as the waters rise and may reach a height of 12 to 20 feet.

In temperate regions short-season varieties maturing in 85 to 145 days are grown. They are usually hardy, somewhat short-stature types that can withstand wide variations in daily temperatures and will produce satisfactory yields when grown in cold irrigation water.

Soil Types

Rice is grown on a wide range of soil types. The water requirements are more apt to be limiting factors than are soil types. The pH range varies from 4.0 to 8.0 (Ghose *et al.* 1956). Soils with impervious subsoils capable of holding flood water are desired when the crop is grown under flooded conditions. Flat river bottom lands or level prairies that can be readily flooded make ideal rice lands.

The soils used for commercial rice production in the United States are usually comparatively level and have reasonably good surface drainage. Medium or heavy clays, clay loams, silt loams or fine sandy loams with slowly permeable subsoils are preferred. Such soils can be flood-irrigated more efficiently and will support heavy mechanized equipment under a wider range of soil moisture conditions than lighter soils. Soils of this type occur in the coastal prairie region of southwest Louisiana and southeastern Texas (Walker and Miears 1957). They also occur in the Grand Prairie and other areas in eastern Arkansas, elsewhere in the south central states and in the interior valleys of California. The rice plant has a high

alkali tolerance and is sometimes grown for reclaiming such lands (Efferson 1952).

Water Requirements and Irrigation

The commercial rice crop of the United States is grown as an irrigated crop, and fields are kept flooded throughout the greater part of the growing season. The rice plant requires abundant soil moisture and usually thrives under continually flooded soil conditions. This requires an abundant supply of readily available irrigation water throughout the growing season. Flooding of fields provides a means of controlling many serious weed pests and assures adequate moisture at all times for optimum growth and development of the rice plant.

FIG. 32. HEAVY OFF-SET DISKS ARE FREQUENTLY USED IN PREPARING LAND FOR RICE PRODUCTION

The total water requirements of a rice crop vary greatly depending upon the type of soil, climatic conditions and the efficiency of irrigation systems. Davis (1950) estimates that from 4 to 10 acre-feet of water are required to produce a rice crop in California. Jones *et al.* (1952) reports that 40 to 45 inches of water are required in Texas and Louisiana and about 33 inches are required in Arkansas. The water requirements supplied by rainfall during the growing season amount to about 15 inches in Texas and Louisiana, about 11 inches in Arkansas and a negligible amount in California.

In the Southern States the land may be drained one or more times during the growing season, but in California the land is rarely drained from the time the seed is sown until it is drained for harvest. The rice plant also grows well under non-flooded or upland conditions. In parts of South America and Asia upland rice is an important crop. Efferson (1952) states that much of the South American rice crop is grown under non-flooded or upland conditions. Upland rice is grown throughout Asia, but it constitutes only a small percentage of the total acreage. Short-season varieties usually maturing in 100 to 125 days are used. The land is cleared and the rice grown during seasons of frequent rainfall. After several crops, yields usually drop off due to reduced fertility and the intrusion of weeds. The area is then abandoned and another area cleared. Yields are low, but little effort is required to produce a crop. In the United States small acreages of upland rice are grown in Alabama, Florida, Georgia, Mississippi and South Carolina, but they now constitute less than one per cent of the total United States rice crop. In the United States upland rice is grown as a cultivated crop sown in rows $1^1/_2$ to 3 feet apart (Jones *et al.* 1943).

Irrigation water is obtained from bayous and streams and from deep wells. According to Adair and Engler (1955), over 40 per cent of the 1953 United States rice crop was irrigated from wells. They estimated the percentage of the crop irrigated from wells to be about 90 per cent in Arkansas, 40 per cent in Louisiana, 20 per cent in Texas and 10 per cent in California.

In Texas and Louisiana surface water obtained from bayous and streams is pumped into canals which usually flow by gravity into laterals leading to the rice fields. The size of the irrigation systems varies from a few thousand acres to over 45,000 acres, and the water is lifted as much as 50 feet into the canals.

In some sections of Arkansas, Louisiana and Texas small pumping systems are installed which elevate surface water from streams and ditches into reservoirs during periods of abundant surface water supply. The water is either pumped or flows by gravity to the rice fields as needed.

In California most of the water used for rice irrigation is directed from large streams. Since the water is usually rather cool, warming basins are frequently used to raise the water temperature before irrigating the fields. Hardy japonica-type varieties are grown in California to help overcome this condition.

Range of Cultural Practices and Rotation Systems

In Asiatic countries, essentially all rice is produced by intense hand methods of production. The land is usually plowed and puddled under

flooded conditions, using oxen. The rice is either sown direct or transplanted to fields from previously sown seedbeds. In many areas rainfall is depended upon for irrigating the crop. Hand harvesting, threshing and milling practices are followed. As a result, an average of over 200 man-days are required to produce an acre of rice.

In the United States highly mechanized production methods are used which require less than two man-days to produce an acre of rice. Much the same general type of equipment is used as for producing other small grain crops, except that flood irrigation must be provided for. Flood irrigation is accomplished by leveling the land and then building contour levees or dykes which are located by survey and usually placed at contour differences of two-tenths of a foot in the southern states and at three-tenths of a foot in California.

Fig. 33. Preparing the Seedbed With a Spring-Tooth Harrow

In India, Pakistan, Ceylon and other Asiatic countries, rice has been cropped continuously on the same lands for centuries. Yields are usually low under these intense cropping conditions where only limited fertilizer materials are used. In Japan, lands produce a rice crop every year but soil-building crops and other forms of fertilizer materials are used. In Spain, Italy and Portugal rice is grown in rotation with pasture and green manure crops combined with heavy applications of fertilizers on both the rice and pasture crops.

In the United States lands are not cropped continuously to rice year

after year. Rotation systems include a wide variety of other crops. The frequency of rice in the rotation system varies with the soil type and with the economic conditions affecting the price or demand for rice. As a general rule, heavy clay soils can be cropped more frequently than lighter soils. Since acreage controls were enacted in 1955, fewer rice crops are grown in the rotation systems throughout the country. More emphasis is being placed upon those practices that result in higher acre yields of rice and more efficient production.

Since the beginning of rice production in Texas and Louisiana, it has been a common practice to grow one or possibly two rice crops, followed by one or more years of grazing beef cattle on the vegetation volunteering between rice crops. Until recent years little effort was made to drain the fields until they were again prepared for rice. Today the most common rotation system used in Texas and Louisiana is rice followed by improved or unimproved pasture for beef cattle grazing. As drainage facilities have improved, more acres are being put into improved pasture when not in rice. While unimproved pasture rotation systems are still the most commonly used practice, improved pastures are gradually increasing in use. In Texas and Louisiana Evatt and Weihing (1957) and Walker and Miears (1957) report that rice following improved pastures yielded 648 to 810 lbs. (4 to 5 barrels) more than rice following unimproved pastures using similar rates of fertilizers.

Improved pastures are usually followed by two or more rice crops. Due to the high cost of developing improved pastures, a field should be cropped to pasture at least three years before cropping to rice. Costs of converting rice lands to improved pastures are reduced by seeding pasture crops immediately following rice without seedbed preparation (Moncrief and Weihing 1950). The rice irrigation and drainage system is maintained when the land is in improved pasture. The leading crops for improved pastures according to Weihing *et al.* (1950), include White, Persian and Hop clovers, Bermudagrass and Dallisgrass. Hay crops such as lespedeza, Alyce clover and ryegrass are sometimes used in rotation with rice, particularly on the lighter, better-drained soils. Cotton, soybeans, peanuts and corn are occasionally grown in rotation with rice in Texas and Louisiana.

The leading crops grown in rotation with rice in Arkansas are soybeans, lespedeza and oats (Jones *et al.* 1952 and Mullins and Slusher 1951). They are usually grown as cash crops, but soybeans and lespedeza are sometimes used as green manure crops. Rice is grown on alternate years or every third year, depending upon economic conditions and the fertility level of the soil. Unimproved pasture and summer fallow rotations are occasionally used in Arkansas.

As late as 1950 no definite rotation system was used in California (Jones *et al.* 1950). It is difficult to grow cultivated crops following rice in California because the soils used are heavy clays that are difficult to work following the long flooding period. It is not always profitable to grow corn, cotton, grain sorghum or beans in rotation with rice. Wheat and barley, the crops grown on rice lands prior to rice culture in California, are sometimes grown in a three-year rotation with rice, with one year of summer fallow following the rice crop. Rice and summer fallow in alternate years are also used. In such cases the land is spring-plowed following rice and summer fallowed until prepared for rice the following spring. In some cases the land is not summer-fallowed but the volunteer vegetation is grazed by cattle or sheep.

FIG. 34. THE AIRPLANE IS USED FOR SEEDING MUCH OF THE UNITED STATES RICE CROP BY DROPPING SPROUTED SEED IN FLOODED FIELDS

Field Irrigation System and Drainage

One of the first steps in preparing land for rice production is the location of field laterals and drainage ditches. It is essential that irrigation laterals and drainage ditches be properly located to afford uniform submergence and timely drainage of fields. Contour levees which divide fields into sub-fields or paddies are located by survey and usually placed on grade differences of two- or three-tenths of a foot. Contour levees are located after the land has been plowed and leveled.

The contour levees are constructed in several ways, depending upon the soil type and the irrigation practices to be used. On the lighter soil types in Arkansas, Louisiana, Mississippi and Texas, disk levee builders are used and usually require two or more passes to form a suitable levee. On the heavier soils in Louisiana and Texas, hydraulically controlled steel blade pushers are used. These pushers are custom built in local machine shops. The levee area is plowed to the center, using a mold board or disk plow before pushing. A second plowing and pushing is required under most conditions. When possible, levees should be formed in the fall or early winter to prevent washouts when fields are flooded.

In California, extremely large pushers or dikers, which form a levee in one or two operations, are commonly used. They require much power or the equivalent of two large track-type tractors. In California, the levees are usually 14 to 16 feet wide including bar-ditches, and 3 to 4 feet high. In the Southern States, levees are seldom over 10 to 12 feet wide and 2 feet high.

Land Preparation

Rice lands may be plowed in the summer, fall, winter or even in the spring just prior to seeding. Summer and fall plowing are practiced as a means of weed control when land cannot be used profitably for growing another crop.

In the Southern States some of the heavier soils are plowed when wet, particularly during seasons of above normal rainfall. The soil should be completely saturated with moisture before plowing.

Much of the rice land is now levelled, using land planes up to 60 feet in length. Where there is considerable fall to the land, shorter land planes are generally used. Land levelling has proved to be extremely profitable, since level land is easier to drain and irrigate. Rice fields should be drained thoroughly when the young rice seedlings are emerging from the soil and again when the fields are drained for harvest. Unless the land is completely level, standing pools may remain. It is important to have a uniform depth of irrigation water on the fields to control weeds and grass properly and to prevent damage to the rice crop.

Lands are made ready for seeding by disking and harrowing. Heavy offset disks perform best on the heavier soil types. Custom built spike-tooth harrows made from pipe are frequently used along with spring-tooth harrows as a final operation prior to seeding. The land is usually left rough or slightly cloddy, as finely prepared seedbeds are more likely to crust following flooding or rains and they also stimulate the germination of small seeded grasses and other weed pests.

Seeding Procedures

Most of the United States rice crop is sown in April and May. In Texas and Louisiana, where a longer growing season prevails, some rice is sown in early March and some after mid-June.

A wide range of seeding methods is used. In California, the airplane is used for seeding practically all of the crop. This has been the practice for over 20 years. In the Southern States, conventional grain drills, the airplane and other broadcast seeding devices are used. The airplane is gaining popularity in the southern states but probably was used for seeding less than one-half of the acreage in 1958.

Rice is sown in both flooded and dry seedbeds. When sown in water, the airplane is used exclusively; but when sown on dry land the grain drill, airplane or some other broadcast seeding device may be used.

FIG. 35. A FIELD OF LODGED RICE

Dryland seedbed preparation and seeding operations follow closely those used with other cereal crops. When the airplane is used for dryland seeding, the seeds are usually covered using a light spike-tooth harrow.

Water-seeding methods vary greatly in the different states. The procedure was first used in California as a means of controlling water grasses (Echinochloa and Leptochloa species). The California method consists of holding flood water from 6 to 8 inches deep on the fields until the seedlings have emerged through the water (Finfrock and Miller 1958). The water depth used depends upon the kind and abundance of

water grasses. It is important to maintain uniform water depths for the first 21 to 28 days following seeding, as the grass will emerge through shallow depths of water. Under California conditions, the deep water also serves as a temperature regulator and thus compensates for the wide variation between prevailing day and night temperatures. After the rice seedlings emerge, an average water depth of 5 to 7 inches is usually maintained throughout the growing period. In cases of excessive vegetative growth by the rice, which may occur on highly fertile land, the fields may be drained when the rice is 60 to 75 days old (Davis 1950).

A number of seeding procedures are followed in the Southern States, depending upon the type of soil, the weed and grass problem and seasonal conditions. Where weeds and grass are not serious problems and weather conditions permit, rice is often sown with a grain drill in rows 7 to 8 inches apart. In clay soils shallow seeding depths are used, and the fields are irrigated immediately following seeding. In sandy loam soils the rice is sown two or more inches deep in moist soil so that it will come up to a stand without irrigation.

Broadcast seeding on dry soil by airplane or various types of broadcast seeders is frequently practiced on the heavier soils. When sown in this way, seedbeds are left rough and harrowed with a light-weight spike-tooth harrow following seeding and prior to irrigating. Irrigation water is applied and drained off as soon as possible. Thorough drainage of fields is essential, as rice seeds covered with soil cannot emerge through water.

Water seeding is used in the Southern States in controlling certain water grasses and Red rice, a variety of rice which volunteers from one rice crop to the next by remaining viable in the soil. In the southern states, rice has more difficulty emerging through water than in California due to the warm water temperatures, cloudy weather, seedling diseases, varieties used, and possibly other factors. In Louisiana and Texas, the flood water is drained off immediately following seeding or dropped to shallow depths until seedlings have emerged and the rice root systems are firmly established in the soil.

The method of water-seeding commonly used in Texas consists of dropping dry or sprouted seeds by airplane in flooded fields that have been harrowed or slightly puddled prior to seeding (Anon. 1951). Light-weight spike-tooth or spring-tooth harrows, pulled by wheel-type tractors operating in shallow flooded fields, are used for this operation. Seeds are dropped 12 to 36 hours after puddling, and fields are drained 12 to 36 hours after seeding. The young seedlings develop rapidly under such conditions, ahead of the weeds and grass. The fields are again flushed a week to 10 days later, depending upon weather condi-

tions and the growth of the rice. Flood water is held as soon as evidence of weeds and grass appears, which may be before the rice seedlings reach a height of 3 to 4 inches. If weeds are not a serious problem, it is better to wait until rice seedlings are 5 to 6 inches tall before holding a flood, regardless of the method of seeding used.

In some sections of Arkansas, Louisiana and Texas water-seeding is used and the land is not worked following irrigation. The water is held for several days after dropping sprouted or dry seed. In most cases the fields are then drained or water is lowered to shallow depths to enable the root systems of the young seedlings that are on the surface of the soil to become established.

FIG. 36. SELF-PROPELLED COMBINE AND SELF-PROPELLED CART

In the Southern States wet seedbed preparation or water cultivation is sometimes necessary during seasons of heavy rainfall. Disks and harrows are used to work the land under flooded conditions, and seeds are then dropped by airplane in flooded fields.

Sprouted seed, when used in water-seeding, should be just breaking the husk. Longer sprouts are likely to be damaged in handling or in seeding. Seeds are sprouted by placing loosely sacked rice in canals or ditches for 12 to 48 hours, followed by a draining period of 12 to 24 hours. The soaking and draining period is dependent upon prevailing temperatures. The soaked rice is usually placed on a truck during the draining period. It may be necessary to sprinkle or pour water over the

sacks to lower the temperature during warm weather. In California, soaking vats are sometimes used for sprouting seed (Davis 1950).

Much of the seed rice used in the Southern States is treated with fungicides. The most commonly used chemicals are Ceresan, Arasan and more recently the liquid mercury type seed treatments. Insecticides such as DDT, aldrin and dieldrin are sometimes used as seed treatments in the Southern States to control insects affecting the rice crop in the seedling stage (Bowling 1957).

Seeding rates vary from 80 to 140 lbs. per acre in the Southern States (Jones *et al.* 1952). In recent years, seeding rates as low as 60 lbs. per acre have been used in the western part of the Texas rice area (Hodges 1957). In California seeding rates vary from 125 to 150 lbs.

Fertilizers

Commercial fertilizers are widely used throughout the rice regions of the United States. The use of commercial fertilizers dates back to the early 1900's, when basic slag and superphosphate were used to a limited extent on relatively new lands in the Southern States. Prior to World War II, the importance of nitrogen fertilizers was recognized (Wyche 1941 and Davis and Jones 1940) and today large quantities of nitrogen and phosphate fertilizers, as well as a limited amount of potash, are used.

In Texas and Arkansas up to 80 lbs. of nitrogen per acre are widely used along with approximately 40 lbs. of P_2O_5. In Louisiana and Mississippi slightly lower nitrogen rates are used. In California 60 lbs. of nitrogen per acre are generally used on soils of average fertility. Lower amounts of fertilizer are required on the more fertile soils.

Rice responds best to ammonia forms of nitrogen, a fact that is recognized throughout the world.

In the Southern States most fertilizer materials are broadcast by airplane after the rice has been sown, as better weed and grass control is obtained by fertilizing after the rice has emerged from the soil and just ahead of the first flood water. Reynolds (1954) recommends that all fertilizer be applied as a top-dressing 35 to 40 days after seeding where grasses and weeds are troublesome. In California most of the fertilizer is broadcast just prior to seeding.

Weeds

Weeds must be constantly guarded against in United States rice fields. Control practices through rotation systems, grazing, summer tilling, water-seeding and timely irrigation and drainage have long been used in the rice-growing regions. Until the advent of chemical weed control,

broad-leaved weeds were gradually becoming worse on heavily cropped lands, particularly in the Southern States. Many farms were so badly infested that it was no longer profitable to grow rice. Since chemical control has been used, many of the water loving broad-leaved weeds so common in rice fields a few years back are no longer a threat to the rice industry.

Both ground and airplane spraying are practiced, but the airplane is much preferred where it can be used without damaging nearby sensitive crops. The leading compounds used are 2,4-D, MCP and 2,4,5-T applied at the rate of $^1/_2$ pound acid equivalent per acre (Davis 1954 and 1955). Pre-emergence chemical treatments are also being used to a limited extent for controlling annual grasses.

FIG. 37. RICE-DRYING PLANT SHOWING THE LARGE COLUMNAR DRIERS AND A QUONSET STORAGE BUILDING

There are many serious weed pests that are not easily controlled by chemical means. They include annual grasses such as Echinochloa and Leptochloa species, and certain broad-leaved water weeds. The more common rice weeds are shown in Table 30.

Red rice is a serious weed pest in many sections of the rice-growing states. It is similar to cultivated varieties in many respects but tillers more profusely than most United States varieties, shatters easily and the grains show a marked dormancy following ripening. As a result, the grains of Red rice remain viable in the soil for several years.

TABLE 30

THE MORE COMMON WEED PESTS FOUND IN UNITED STATES RICE FIELDS[1]

Common Name	Scientific Name
Grasses	
Red rice	*Oryza sativa*
Big Barnyard (Cockspur)	*Echinochloa crusgalli*
Little Barnyard (Jungle rice)	*Echinochloa colonum*
Sprangletop	*Leptochloa Fasicularis*
Rice cutgrass	*Leersia oryzoides*
	Leersia hexandra
Large crabgrass	*Digitaria sanguinalis*
Jointgrass	*Paspalum distichum*
Longtom	*Paspalum lividum*
Sedges	
Bulrush	*Scirpus fluviatilis*
Elegant cyperus	*Cyperus sabulosus*
Yellow cyperus	*Cyperus iria*
Yellow nutgrass	*Cyperus esculentus*
Jointed sedge	*Cyperus articulatus*
Umbrella plant	*Cyperus verins*
Spikerushes	*Eleocharis spp.*
Spearhead	*Rhynchospora corniculata*
Hurrah grass	*Fimbristylis miliaceae*
	Fimbristylis puberula
Leguminous weeds	
Tall indigo	*Sesbania macrocarpa*
Coffee bean	*Sesbania drummondi*
Spunk bean	*Sesbania vesicaria*
Curly indigo	*Aeschynomene virginica*
Sickle senna	*Cassia torra*
Other weeds	
Alligator weed	*Alternanthera philoxeroides*
Arrowhead	*Sagittaria spp.*
Batwing (Day flower)	*Commelina communis*
Cattail	*Typha latifolia*
Curly dock	*Rumex crispus*
Eryngo (Star thistle)	*Eryngium hookeri*
Large Buttonweed	*Diodia virginiana*
Mexican weed (Birdeye)	*Caperonia palustris*
Mud plantain	*Heteranthera limosa*
Redstem	*Ammannia coccinea*
Redweed (Goat's Beard)	*Melochia corchorifolia*
Seacoast sumpweed	*Iva ciliata*
Seaweed	*Sphenoclea zeylanica*
Sida or ironweed	*Sida spp.*
Slim aster	*Aster exilus*
Snow-on-the-prairie	*Euphorbia bicolor*
Water hyssop	*Bacopa rotundifolia*
Water plantain	*Alisma plantago*
Water primrose	*Jussiaea spp.*
Wooly croton (Goatweed and Turtle back)	*Croton capitatis*

[1] Compiled from information reported by Davis (1950), Hodges (1957), Williams (1955 and 1956), and from a weed collection maintained at the Rice-Pasture Experiment Station, Beaumont, Texas, which was collected by Mrs. Betty Higinbotham (not published).

Diseases

There are a number of diseases attacking the rice plant in the Southern States, but they seldom cause heavy losses. The only serious disease that attacks rice in California is seedling blight.

Fig. 38. Drying Plant With Concrete Storage Bins

One of the most serious diseases in the Southern States is straighthead, a physiological disease (Atkins 1958 and Tisdale and Jenkins 1921) which is most prevalent on lighter soil types or where large amounts of organic matter have been added to the soil and are not completely decayed. Straighthead is characterized by panicles that remain erect because the grains fail to develop properly. The panicles may be distorted and glumes deformed or in extreme cases the plants may fail to head. The disease can be controlled or greatly reduced by draining fields at about the jointing stage of growth (Cheaney 1955) and by growing resistant varieties (Atkins *et al.* 1956).

A number of leaf spot diseases (*Helminthosporium oryzae, Cercospora oryzae, Entyloma oryzae*) caused by fungi are common in the Southern States, but they seldom cause losses of economic importance (Atkins 1958). Stem rot (*Sclerotium oryzae*) occasionally causes rather severe losses from lodging and from failure of grains to fill properly.

Blast (*Piricularia oryzae*), one of the most prevalent rice diseases throughout the world, also occurs in the Southern States, but losses are seldom severe. The varieties now grown are moderately resistant to blast, but on new lands or when extremely heavy amounts of nitrogen are present the disease can become severe. This is particularly true during periods of cloudy, humid weather accompanied by relatively high night temperatures. This disease can usually be controlled by growing the more resistant varieties.

White tip, a disease caused by a seedborne nematode (*Aphelenchoides besseyi Christie*) (Atkins 1958), causes rather severe losses on susceptible varieties. Most of the varieties now grown are resistant or moderately resistant to white tip. The most satisfactory control measures are hot water treatment of seed (Cralley 1949), along with the use of resistant varieties.

Recently a new virus disease, hoja blanca, has been discovered in Florida (Atkins and Adair 1957), but the disease has not been found in the important rice-producing states. It has caused heavy losses in Cuba, Venezuela and Colombia in recent years. Varieties resistant to hoja blanca have been found. Unfortunately, all of the leading commercial United States rice varieties are susceptible to this disease. The hoja blanca disease is carried by a leaf hopper (*Sogata orizicola*) (Acuna 1958 and Atkins 1958). This particular *Sogata* species has not been found in the major rice-growing states but has been found in Florida. Hoja blanca-resistant short- and medium-grain varieties that appear to be reasonably well adapted to growing in the United States have been found. Many of the resistant varieties are introductions from Japan and Formosa. It should be possible to develop, through breeding, adapted varieties of all grain types that are resistant to hoja blanca. The hoja blanca disease resembles in some respects the stripe virus disease (Oryza virus 2) occurring in Japan.

Insects

Several species of field insects attack the rice plant, particularly in the Southern States. The most common rice insect pests are rice water weevils, army worms, rice stalk borers, the rice stinkbug, leaf miners, the sugarcane beetle and grasshoppers. The rice water weevil, or root maggot (*Lissorhoptrus oryzophilus*), attacks young seedlings by feeding upon their leaves in the adult stage and by feeding upon the roots in the larval stage. The adults deposit their eggs in the roots of the rice plant immediately after the first flood water has been applied. The fields must remain flooded for the larval stage (maggots) to develop. The maggots feed upon the young roots and cause serious damage to the rice root system. Control measures are: timely draining of fields (Isely and Schwardt 1934); the use of insecticides such as aldrin or dieldrin as seed treatments (Bowling 1957); or spraying fields (Whitehead 1954).

Army worms can cause serious damage to rice by devouring the leaves and stems. They are easily controlled by aerial application of various insecticides. The two stalk borers affecting rice are the sugar cane borer (*Diatrae saccharalis*) and the rice stalk borer (*Chilo plejadellus*) (Douglas and Ingram 1942). Heavy losses seldom occur, but borers are found

in most rice fields. They feed within the rice stems during the jointing and heading stages of development and cause the panicles to dry up and turn white. This usually occurs before the grains are fully developed. There are no practical means of control.

The rice stinkbug (*Solubea pugnax*) and several other related species cause serious losses to the developing rice grain by puncturing the grain in the milk or dough stage. Losses result from grain failing to develop and from the discoloration caused by the puncture and accompanying fungal infection on grains which do develop. Many of these damaged grains are poorly filled and break up in the milling operation and thus

FIG. 39. RICE IS DRIED ON THE FARM BY FORCING UNHEATED AIR THROUGH THE STORAGE BINS

reduce head or whole grain rice yields. Punctured grains which fill properly are not apt to break in milling and result in a reduction in quality and appearance due to the discoloration. This is commonly referred to by the rice trade as "pecky rice." Stinkbugs and similar insects can be controlled by airplane spraying with recommended insecticides such as aldrin, dieldrin and toxaphene (Bowling 1956).

Grasshoppers cause damage to rice by feeding upon the glumes and other floral parts of the developing rice grain. They can be controlled by airplane spraying with insecticides.

Leaf miners affect rice plants in the seedling stage and in cases of heavy infestations they can cause serious reductions in stands.

The sugarcane beetle (*Euetheola rugiceps* (Lec.)) is most severe in southwestern Louisiana but also occurs in the other southern rice-growing states, according to Douglas and Ingram (1942). The adult beetles attack rice plants in both the seedling and mature stage by feeding on the lower stems when rice is not flooded.

Harvesting

Rice is harvested from late July to late October in Texas and Louisiana. In Arkansas and California the harvest season is shorter due to the shorter growing seasons.

Self-propelled combines are commonly used for harvesting rice in all of the rice-growing regions. Conventional combines are used throughout the Southern States and parts of California, with minor changes to adapt them to muddy harvesting conditions. In California large custom-built full-track combines are sometimes used (Davis 1950). These machines are built in farm shops in the rice areas. Pickup reels are now standard equipment on most rice combines as lodging is frequent, especially where high rates of nitrogen fertilizers are used.

Rice is usually harvested when the moisture content of the grain is between 18 and 25 per cent. Therefore, it is necessary to dry the grain artificially before placing it in permanent storage. If the rice is harvested at higher than 20 to 25 per cent moisture content, there may be immature grains on the lower portions of the panicles which will be chalky and may break in milling. When harvested at moisture contents below 18 per cent, the grains are more apt to check or fracture, resulting in reduced whole grain yields when milled. Checking of grains is caused by alternate wetting and drying of the rice grains from showers or heavy dews, accompanied by wide variations in temperatures.

As a general rule, rice is harvested at higher moisture contents in California than in the Southern States. This is done because the shorter, fuller grain varieties grown in California are probably more apt to check or fracture. The wide extremes in day and night temperatures and humidity are conducive to fracturing of grains when moisture contents drop below 20 per cent.

Rice fields often are muddy or otherwise inaccessible to motor trucks at time of harvest. Therefore, some means of conveying the threshed rice from the combine to the trucks must be used. For this operation various types of conveyor bins, tanks or carts are used. The most popular means of conveyance in recent years has been self-propelled carts or tanks, custom-made in farm shops. In California track-type tanks are sometimes used, but in the Southern States wheel-type carts are generally used.

DRYING AND STORAGE

Combine harvested rice is cut at a relatively high moisture content and consequently must be dried before it can be placed in permanent storage. Since rice is marketed as a whole grain product, it is important that the grains not be fractured or otherwise damaged before or during the drying

FIG. 40. PHYSICAL AND CHEMICAL TESTS ARE USED FOR DETECTING VARIETAL DIFFERENCES IN GRAIN PROCESSING AND COOKING CHARACTERISTICS

process. Large column-type, continuous-flow driers using heated air as well as batch-type units have been widely used.

In recent years, "on the farm bin drying," using unheated air, has been successfully used throughout the rice-growing states (Morrison *et al.* 1954, Sorenson and Davis 1955 and Hildreth 1955).

Some rice has also been dried in sacks, using heated air in tunnel-type driers. Today, due to high handling costs, sack drying is for the most part limited to drying seed rice. It affords a means of drying with a minimum chance of mixing, which is vitally important in maintaining high quality seed rice.

The column-type methods of drying rice consist of passing heated air through falling or stationary columns of rice for short periods of time. It usually requires two or more passes through the drier to bring the mois-

ture content down to 12.0 to 13.5 per cent, which is usually considered satisfactory for safe storage.

The maximum temperature of heated air used in column-type driers seldom exceeds 266°F., according to Barr and Coonrod (1951). Kramer (1948) reports that air volumes of 400 cubic feet per minute per barrel of rice are commonly used.

Most column-type units are relatively large commercial plants and frequently dry over 120,000 hundredweight of rough rice annually. Considerable storage space is required to handle such quantities of rice, even though a major part of the rice may be shipped from the drier as soon as the rice has been dried. In order to make more efficient use of drying facilities, most commercial drying plants now have ventilated holding bins that allow high moisture rice to be held for longer periods before drying.

Bin drying has been increasing in popularity in recent years. Both round bins and quonset-type bins have been used with equal success. Large volumes of air must be forced through the rice when dried in this way. The minimum airflow rate recommended by Sorenson and Davis (1955) was 9.0 cubic feet of air per minute per barrel (162 lbs.) forced through an 8-foot depth of rice. The rice is dried to 13 per cent moisture or less. It is of interest to note that this method of drying can be successfully used in the Gulf Coast areas of Texas and Louisiana where periods of relatively high humidity are not uncommon.

Practically all of the United States rice crop is stored in bulk. Prior to World War II, most of the Texas and Louisiana crop was sacked as it was threshed, using stationary threshing machines. The grain was stored in sack warehouses. However, when combine harvesting and artificial drying replaced the binder-thresher method of harvest, there was a rapid shift to bulk storage. Varied and different types of structures are used including wood, concrete and steel bins.

The maximum moisture content for safe storage of rough rice is approximately twelve per cent in any part of the bin, according to Sorenson and Davis (1955). Moisture contents as high as 14 per cent for the wettest grain in the bin have been recommended for temporary winter storage (Anon. 1950). Forced ventilation is widely used throughout the rice-growing regions for keeping stored rice in condition in both on-the-farm and commercial storage units.

VARIETIES

The varieties of rice grown in the United States are comparatively short-strawed, intermediate tillering types. This is in contrast to the lush-growing, profuse-tillering, long season varieties grown in the Tropics.

TABLE 31

VARIETIES OF RICE GROWN IN THE VARIOUS STATES IN 1957 AND THE PERCENTAGE OF THE UNITED STATES TOTAL OF EACH VARIETY AND GRAIN TYPE REPRESENTED[1]

Variety	Per Cent of United States Production (1957 crop)							
	Arkansas	Louisiana	Mississippi	Texas	Southern States	California	Other States	United States Total
Long-grain varieties								
Bluebonnet 50[2]	10.08	8.78	1.50	10.66	31.02		0.11	31.13
Century Patna 231	3.46	1.00	0.59	10.82	15.87			15.87
Rexoro-Texas Patna[3]		1.49	0.02	3.13	4.64			4.64
Toro	0.09	4.02		0.39	4.50			4.50
Rexark	0.18				0.18			0.18
Total	13.81	15.29	2.11	25.00	56.21		0.11	56.32
Medium-grain varieties								
Zenith	7.50	7.07	0.22	0.08	14.87		0.22	15.09
Magnolia		2.48		0.07	2.55			2.55
Roses[4]	1.49				1.49			1.49
Nato	0.16	0.29			0.45			0.45
Total	9.15	9.85	0.22	0.15	19.36		0.22	19.58
Short-grain varieties	1.44				1.44	21.54[5]		22.98
Other varieties not classified			0.02		0.02	1.10[6]		1.12
Grand Total	24.40	25.13	2.35	25.15	77.03	22.64	0.33	100.00

[1] From Anon. (1958).
[2] Includes a small acreage of Sunbonnet, Improved Bluebonnet and Bluebonnet.
[3] Includes Rexoro, Texas Patna and TP 49.
[4] Mostly Arkrose and a small amount of Kamrose.
[5] California short-grain acreage is 85 to 90 per cent Caloro and 10 to 15 per cent Colusa.
[6] Mostly Calrose.

United States varieties can be divided into early, midseason and late-maturing groups, based on the number of days from seeding to maturity. Early-maturing varieties mature in approximately 120 days, midseason-maturing varieties in 140 days and late-maturing varieties in 170 days. Today, most of the acreage is sown to early- and midseason-maturing varieties. It is only in Texas and Louisiana that the late-maturing long-grain varieties are grown. Even here they are becoming less popular because of the long watering period and because they seldom yield as high as the early- and midseason-maturing varieties. The late-maturing varieties do possess certain grain characteristics not found in other commercially grown varieties. As a result, they usually bring premium prices. Late-maturing varieties such as Rexoro, Texas Patna and TP 49 are better suited for parboiling and canning than other varieties because the grains remain firmer and show less splitting when processed. This is thought to be a heritable character and has been found in early-maturing foreign introductions.

The varieties of rice grown in the United States are shown in Table 31. It will be noted that the varieties of rice grown in the Southern States, with but few exceptions, differ from those grown in California. This is due to the fact that the two regions have vastly different climatic conditions and require varieties of different adaptation.

In California the short-grain japonica-type varieties are grown because they are hardy types which have the ability to emerge through several inches of relatively cold water when sown in flooded fields. They are also able to withstand the extremes in temperature prevailing in the interior valleys of California. Under California conditions they are well adapted to mechanized harvesting methods.

The varieties of rice grown in the United States have, for the most part, been developed from japonica and indica varieties originally introduced from Japan, the Philippines and Formosa. From these original introductions were selected such varieties as Blue Rose, Early Prolific, Caloro, Colusa, Fortuna, Nira and Rexoro (Jones *et al.* 1953).

The four United States rice experiment stations located at Stuttgart, Arkansas, Biggs, California, Crowley, Louisiana, and Beaumont, Texas, have had active breeding programs for many years. They have been operated cooperatively by the four state agricultural experiment stations, the United States Department of Agriculture and local rice industry organizations. All of the United States rice crop, with the exception of a negligible acreage, is now sown to varieties developed by these organizations.

In recent years hybridization at the United States rice experiment stations has brought about the development of a new group of varieties by

intercrossing commercially grown varieties and by crossing commercial varieties with foreign introductions. Varieties now grown that have been so developed include Bluebonnet, Bluebonnet 50, Sunbonnet, Toro, Century Patna 231, Texas Patna, TP 49, Nato, Magnolia and Calrose. These varieties now constitute approximately 60 per cent of the United States rice crop. The only major varieties not the result of hybridization are Caloro and Colusa, leading California varieties; Zenith, the leading medium-grain variety grown in the Southern States; and Rexoro, one of the leading late-maturing long slender grain varieties grown in Texas and Louisiana.

Some of the newer varieties of rice now grown in the United States have been developed by crossing japonica and indica varieties in order to combine the desirable features of both groups. Varieties developed from such crosses are Century Patna 231, Toro, Nato and Magnolia. The indica varieties used were, for the most part, long-grain and the japonica varieties were short-grain types.

The japonica varieties are usually recognized as being higher yielding than the indica types (Ramiah and Rao 1953 and Ghose *et al.* 1956). The japonica varieties have small stems, relatively short straw and narrow leaves of short to intermediate length. They usually respond well to heavy applications of nitrogenous fertilizers. The straw of the japonica varieties is tough and willowy and not so desirable for combine harvesting as the more frangible and stiffer straw type of certain of the indica varieties. Also, the japonica varieties do not possess the range of grain size and shape or processing and cooking characteristics needed in United States rice varieties.

Most of the japonica-type varieties are sensitive to length of day, while certain indica types have a more or less fixed growth period (Beachell 1943). By using varieties of a fixed maturity period the harvest season can be spread over a longer period, resulting in more efficient use of expensive harvesting and drying facilities.

Most of the long-grain varieties now grown in the Southern States have a partially dormant period as they ripen, and the grains seldom germinate on the panicle during periods of rainy or humid weather. Japonica varieties usually do not show this tendency. This dormancy lasts for a month or more after harvest, and it is not uncommon for potentially high germinating lots of long-grain varieties to germinate as low as 50 per cent when tested shortly after drying.

The japonica varieties are, for all practical purposes, no longer grown in the Southern States because they are not adapted to combine harvesting methods under prevailing conditions. They produce high yields but lodge severely and are difficult to thresh. The inclement weather pre-

vailing throughout the Southern States during the harvest season requires that a variety not lodge excessively and that the grain thresh freely from the panicles. In California, where the harvest can be completed with little or no rainfall, lodging is not so critical. However, it should be pointed out that under California conditions varieties such as Caloro and Calrose grow much shorter than they do in the Southern States and are less likely to lodge.

The earlier maturing long- and medium-grain varieties grown in the Southern States are not adapted to the extreme temperatures and low humidity of California. While they will mature grain, experimental yield trials reported by Jones *et al.* (1952) show the yields to be relatively low compared with adapted japonica varieties.

Quality Tests Used to Identify Different Varieties

United States rice varieties are divided into short-, medium- and long-grain groups based on grain size and shape. Beachell and Halick (1957) state that each grain type is associated with certain specific processing and cooking characteristics, but that there were exceptions. Most long-grain varieties tend to cook dry and fluffy and the grains do not split or stick together. Short-grain varieties are usually more firm than long-grain varieties and tend to be more cohesive. Medium-grain varieties are usually intermediate in these respects. Beachell and Hallick (1957A) and Halick and Kelly (1958) reported exceptions to the above classifications. The differences in processing and cooking behavior reported were apparently due to inherent differences in the chemical makeup of the rice grain rather than to grain size and shape.

Some of the inherent varietal quality differences found by these and other investigators were amylose content, gelatinization temperature of starch when cooked and stickiness of the cooked product. Williams *et al.* (1958) reported differences in amylose content of from 12.9 to 23.5 per cent. Varieties with high amylose content were Rexoro and Texas Patna. Varieties with low amylose content were Century Patna 231 and Toro. Halick and Keneaster (1956) were able to classify rice varieties as to amylose content, using an empirical starch-iodine blue technique.

Quality differences of milled rice are based upon the yield of total milled rice, yield of whole grain rice, appearance and the processing and cooking behavior of the milled grain. In the United States practically all of the domestic rice crop is milled to a relatively high degree. Milling as practiced in the United States consists of removing the hulls and most of the bran layers. Most of the fats, oils and proteins, located in the bran layers are removed in the milling operation. As a result, the physical and chemical differences in the starchy component of the rice grain are

TABLE 32

VARIETAL DIFFERENCES IN FIELD AND GRAIN CHARACTERISTICS OF THE MORE IMPORTANT UNITED STATES RICE VARIETIES

Variety	Reaction to Straight-Head[1]	Pubescence	Maturity	Grain Type	Grain Dimensions Milled Grains (mm.)			Wt. of 100 Milled Grains	Amylose Content	Gelatinization Temperature of Starch	Cooking Behavior	Cooking Time	Suitability for Parboiling and Canning
					Length	Width	Thickness	Gm.					
Century Patna 231	S	Smooth	Early	Long	7.45	1.99	1.65	1.47	Low	High	Fluffy	Long	V. Poor
Bluebonnet 50	R	Smooth	Med.	Long	7.78	2.16	1.73	1.67	High	Intermed.	Fluffy	Inter.	Fair
Sunbonnet	MS	Smooth	Med.	Long	7.55	2.18	1.75	1.77	High	Intermed.	Fluffy	Inter.	Fair
Texas Patna	R	Smooth	Late	Long	7.28	1.89	1.66	1.58	High	Intermed.	Fluffy	Inter.	Good
Rexoro	VS	Smooth	Late	Long	7.27	1.93	1.66	1.65	High	Intermed.	Fluffy	Inter.	Good
TP 49	VS	Smooth	Late	Long	7.71	2.05	1.71	1.77	High	Intermed.	Fluffy	Inter.	Good
Toro	MS	Smooth	Med.	Long	7.28	2.09	1.61	1.68	Low	Low	Firm	Short	V. Poor
Zenith	S	Hairy	Early	Med.	6.51	2.57	1.74	1.77	Low	Low	Firm	Short	V. Poor
Nato	MS	Smooth	Early	Med.	6.08	2.58	1.76	1.63	Low	Low	Firm	Short	V. Poor
Calrose	R	Hairy	Med.	Med.	5.86	2.38	1.79	1.83	Low	Low	Firm	Short	V. Poor
Colusa	MS	Hairy	Early	Short	5.63	2.81	1.95	1.97	Low	Low	Firm	Short	V. Poor
Caloro	R	Hairy	Med.	Short	5.35	2.82	2.03	2.17	Low	Low	Firm	Short	V. Poor

[1] Classified as S = susceptible; MS = moderately susceptible; VS = very susceptible; and R = resistant.

generally thought to constitute the basis for differences in processing and cooking behavior.

While many environmental factors affect the mill yields of rice, varietal differences are known to occur. Beachell and Halick (1957) report total rice yields varying from 72.6 per cent for Caloro to 65.5 per cent for Century Patna 231, using laboratory test methods. Whole grain yields varied from 60.7 per cent for Toro to 39.5 per cent for Nira. Some of these differences are attributed directly to inherent varietal differences.

Clear translucent grain appearance is preferred to opaque appearance or grains with opaque or chalky centers. The different varieties vary greatly in this respect, but the exact cause of these and other varietal differences is not fully understood.

Physical and chemical differences in the milled rice grain are used in classifying varieties. A number of the more recently reported tests used for classifying varieties using physical and chemical methods will be discussed. These differences along with agronomic differences are shown in Table 32.

Differences in gelatinization and pasting characteristics were reported by Halick and Kelly (1958) using a standard model "amylograph." A slurry of 50 grams of ground milled rice and 450 ml. water was heated to minutes, then lowered to 122°F. at the rate of 2.7°F. drop per minute. After reaching 201°F., temperature was maintained constant for 20 minutes, then lowered to 122°F. at the rate of 2.7°F. drop per minute The salient varietal differences reported were (1) the temperature at which gelatinization occurred, (2) the peak viscosity, (3) the viscosity at 201°F. and, after 20 minutes at this temperature (4) viscosity when cooling to 122°F.

The short and medium-grain varieties such as Caloro, Zenith and Nato and the long-grain variety, Toro, gelatinized at the lowest temperatures. Century Patna 231 and Early Prolific gelatinized at the highest temperatures and Bluebonnet 50, Sunbonnet, Texas Patna and Rexoro gelatinized at intermediate temperatures. Gelatinization temperatures were independent of grain type and amylose content, but it was concluded that there was a direct relationship between maximum viscosity of the hot paste and viscosities when cooling to 122°F. Gelatinization temperatures varied from 149°F. for Zenith to 175°F. for Century Patna 231. A glutinous variety (no name reported) gelatinized at a temperature of 136°F. or lower than any of the common varieties.

Halick and Kelly (1958) also report a rapid method of classifying rice varieties on their ability to absorb water when cooked at different temperatures in excess water. Two-gram samples of whole grain milled rice were cooked at temperatures of 162°, 171°, and 180°F. for 45 minutes

in excess water. Results were reported on the basis of the percentage of water absorbed by weight during cooking. The results obtained show this test to be valuable in determining the approximate gelatinization temperatures of large numbers of varieties and selections in rice breeding programs.

Batcher *et al.* (1956 and 1957) classified rice varieties using cooked samples of whole grain milled rice. Color, cohesiveness, flavor, degree of doneness and amount of water absorbed were recorded. Rexoro, Texas Patna, Bluebonnet 50 and Century Patna 231 all absorbed more water during cooking and were less sticky than Caloro and Colusa. They concluded that grain type appeared to be associated with water absorption but noted some overlapping. Residual cooking liquids from most of the long-grain varieties appeared to have less total solids and starch than the short- and medium-grain varieties. However, Century Patna 231 and Toro had higher amounts of total solids in residual cooking liquids than other long-grain varieties.

Williams *et al.* (1958) made comparisons between the amylose contents of different varieties using a modification of the colorimetric method of McCready and Hassid (1943). Amylose content was found to vary from 12.9 per cent for Century Patna 231, to 23.4 per cent for Texas Patna, both long-grain varieties. The short- and medium-grain varieties Zenith, Magnolia, Nato and Caloro all had below 15 per cent amylose. Toro, a long-grain variety, also showed a low amylose content.

Soaking milled rice grains in dilute solutions of potassium hydroxide has been used by several investigators as a means of detecting varietal differences in milled rice. Warth and Darabsett (1914) soaked short- and medium-grain Asiatic varieties in different concentrations of potassium hydroxide. They found two main groups based on resistance of the rice grains to the alkali solution and in the case of three varieties associated these differences with gelatinization temperatures. Jones (1938) divided United States rice varieties into three groups and concluded that varieties disintegrating into intermediate and clear masses were of preferred cooking behavior to varieties showing opaque masses.

Little *et al.* (1958) classified 25 rice varieties from each of four geographical locations in the United States by soaking milled grains in a 1.7 per cent potassium hydroxide solution. Differences were based on the degree of spreading and clearing of grains, using a 7-point numerical scale. They found that Century Patna 231, a long-grain variety, and Early Prolific, a medium-grain variety, showed the least amount of spreading and clearing and were usually rated 1 and 2 on the numerical scale. The long-grain varieties were found to give variable reactions. The short- and medium-grain varieties, except for Early Prolific, were more uni-

form in reaction, showed more spreading and clearing and were usually scored 6 and 7 for spreading and 5 to 7 for clearing.

A cooking and soaking test reported by Halick and Keneaster (1956) gave marked varietal differences in the degree of longitudinal splitting of the grains. The rice was cooked for 20 minutes and soaked overnight in petri dishes. It was concluded that varieties exhibiting the greatest degree of longitudinal splitting showed the greatest degree of stickiness when cooked.

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Samuel A. Matz

Millet, Wild Rice, Adlay, and Rice Grass

INTRODUCTION

The preceding chapters in this section are concerned with the seven grains which are most important to the economy of the United States. In the present chapter, four cereal grains of minor significance will be briefly discussed. Two of these are plants which are currently grown and the products sold for food or feed, though in small quantities. One of the others is primarily of historical interest, while the fourth has never been used in this country though it has interesting possibilities.

It might be worthwhile to remind the reader of the predetermined limitations of this volume. Only cereal grains are considered, and so buckwheat (an herbaceous plant), soybeans (a legume) and other non-grasses bearing seeds which are commonly processed and consumed similarly to cereal grains are not included. Furthermore, the forage aspects of cereal plants are touched upon only in passing, and the industrial (non-food and non-feed) uses of cereal products are ignored, except where it is necessary to discuss them in order to clarify more pertinent points. The greatest emphasis has been placed upon practices followed in the United States, although there has been no intention of ignoring the more important variations of these procedures found in other countries.

MILLET

The name of millet has been applied, at different times and at different places, to a wide variety of cereal grains. *Sorghum vulgare* has been erroneously called pearl millet and in some parts of the world all varieties of sorghum and millet are designated by the latter name. However, the grains most generally recognized as millets belong to two tribes of the grass family, the Chlorideae and the Paniceae, while sorghums belong to one genus (Sorghum) in one tribe (Andropogoneae) of the grass family.

The tribe Chlorideae includes *Eleusine coracana* as the only species of economic importance (Hitchcock 1950). This plant, called variously African, ragi, or finger millet, is grown very extensively in India where the grain is used as human food. The tribe Paniceae includes several species grown for food and feed in various parts of the world. The most important of these species will be described below.

Setaria (*Chaetochloa*) *italica* includes many varieties such as foxtail millet, German millet, Hungarian grass, Siberian millet, and Kursk millet

Courtesy of U.S. Dept. Agr.

FIG. 41. FOXTAIL MILLET (*Setaria italica*).

which are grown in China or Russia for human use, but in the United States only for forage. *Pennisetum typhoideum*, pearl millet, is extensively cultivated in Egypt and in tropical Asia—particularly India—as a food cereal. *Echinochloa decompositum* is the Australian millet, grains of which are said to be used as food by the aborigines of that continent. Other species of *Echinochloa* are grown for food in tropical Africa and in South America. The only genus of any economic importance in the United States is *Panicum*, and *Panicum miliaceum*, proso or common millet (also called broomcorn millet and hog millet) makes up the largest crop.

The origin of *Panicum miliaceum* is unknown, but it is probably a native of Egypt and Arabia. It has been cultivated in Asia Minor and Southern Europe since prehistoric times. Millet kernels were found among the habitations of the Swiss Lake-Dwellers. It is a small, erect annual, reaching a height of 3 to 4 feet and possessing bristly, much branched panicles. The grain is about 3 mm. long by 2 mm. broad, and is usually inclosed in the shining, hard, flowering glume and palea. The glumes may be red or yellow, or any shade of gray. Three botanical varieties are recognized and designated as *effusum*, *contractum*, and *compactum*.

Soil preparation and cultivation procedures are little different from those used for other cereals. The seedbed is prepared by plowing, harrowing, and cultipacking or otherwise firming the seedbed. The seed can be sown either by drilling or by broadcasting, though drilling is used most extensively. It is sown during the period from late May to early July.

About 60 to 75 days after seeding, millet is ready for harvesting. Ripening is not uniform, and frequently it is found that the grain in earlier panicles or in the tops of the heads are ripe and have shattered before the lower seeds and later panicles are completely mature. Because of the irregular ripening, much seed is lost by direct combining and the usual practice is to cut the crop by a swather. The windrows formed in this manner are allowed to cure, and then combined. The crop can also be harvested with a grain binder and placed in shocks to cure. Thereafter, it is handled like wheat or other small grains. Up to 20 bushels of seed per acre can be obtained under favorable conditions. The weight of the seed is from 48 to 60 lbs. per bushel.

Although millets constitute one of the world's most important groups of food plants, their cultivation is restricted mostly to the Eastern Hemisphere, and, in particular, to regions of rather primitive agricultural practices and high population density. During the Medieval era, it was one of the principal grains produced in Europe. The reasons for its decline in popularity are rather obvious. Meal and other preparations of millet have a strong taste which is not generally preferred by persons having

access to blander grains. Furthermore, the meal cannot be made into leavened bread, so it must be consumed as a gruel or made into flatbread. Higher yielding grasses are available for feed purposes, except where certain rather unusual combinations of soil and climate exist. For example, oats generally outyields millet, except for some areas where sandy soil, hot growing weather, and scanty rainfall combine to make the environment more favorable for millet.

In comparison with wheat, corn, and oats, the production of millet in the United States seems ridiculously small. Most of it is grown in North Dakota, South Dakota, and Colorado, and is of the proso variety. The seed is used in the United States principally for poultry feed, but some is used for stock feed, and a small amount is used in commercial feed mixtures for pet birds such as canaries and parakeets. Occasionally, whole panicles of the plant are sold in pet food stores for hanging in bird cages.

The plant can be grown as far north as 54° N. latitude. However, it does not grow well anywhere until the soil is warm. In northern states, seed may not be sown until late June or early July. The seed deteriorates rapidly, and it is generally considered undesirable for use after more than two years of storage, because of the low rate of germination.

As a general rule, fertilizers are not used with millet in the Great Plains states. Farther east, nitrogen and phosphate applications have caused increased yields, but it appears to be more economical to use the fertilizer on other crops in the rotation.

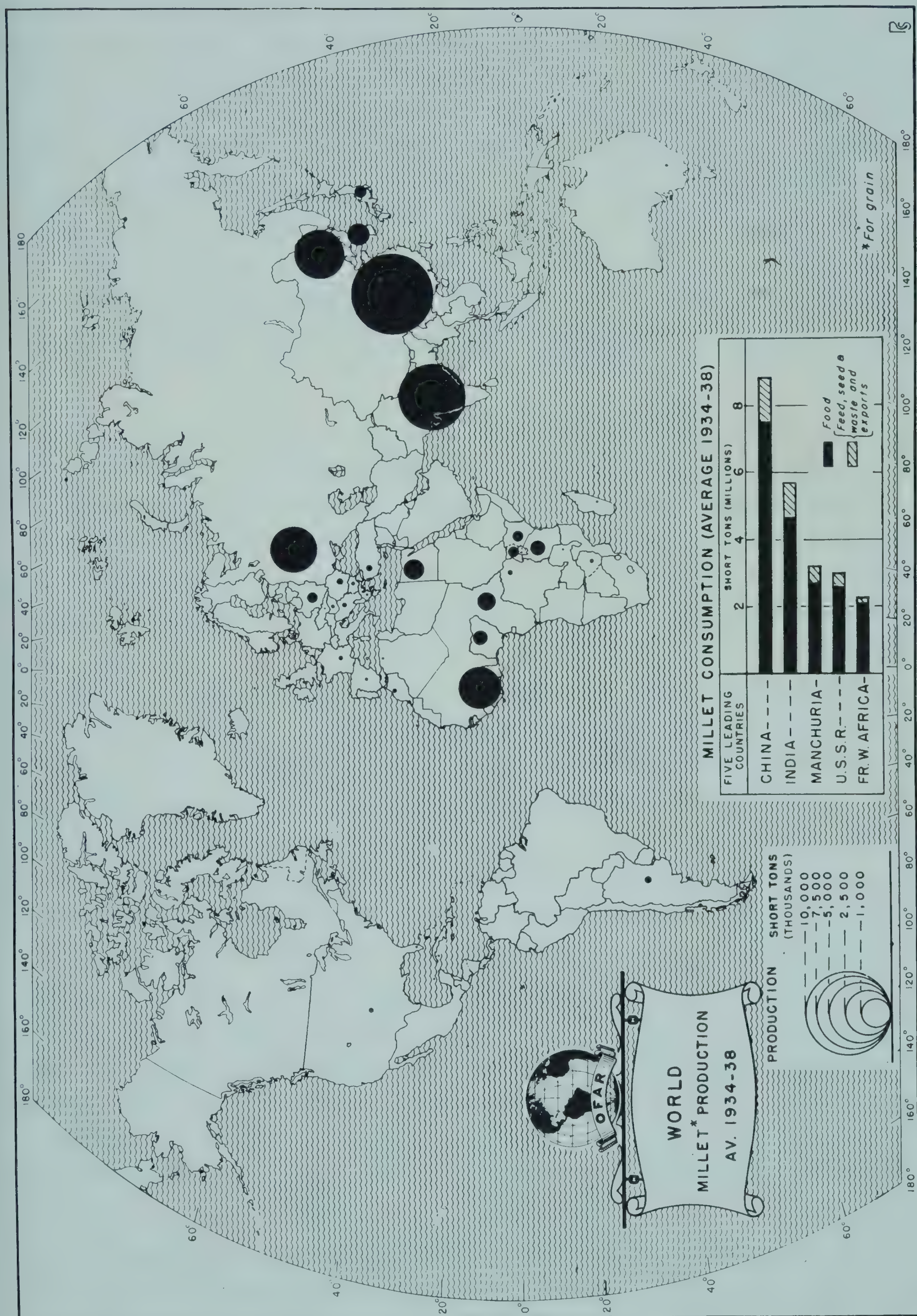
Twenty-five to 40 lbs. of seed per acre are recommended for areas of ample rainfall, while 15 to 20 lbs. per acre should be used in drier localities. The smaller amounts of these ranges are more appropriate where

TABLE 33

AVERAGE COMPOSITION OF MILLET AND OTHER GRAINS[1]

Grain	Average Analysis, Per cent				
	Protein	Fat	Fiber	Carbohydrate, Except Fiber	Ash
Proso millet	11.7	3.3	8.1	64.2	3.4
Foxtail millet	12.1	4.1	8.6	60.7	3.6
Sorghum	11.3	2.9	2.2	71.3	1.7
Adlay[2]	13.6	6.1	8.4	58.5	2.6
Rice (rough)	7.9	1.8	9.0	64.9	5.2
Wild rice[3]	14.1	0.7	1.5	74.4	1.2
Oats	12.0	4.7	10.6	60.2	3.6
Corn	9.7	4.0	2.3	71.1	1.4
Wheat	13.2	1.9	2.6	69.9	1.9
Barley	11.8	2.0	5.7	68.0	2.9

[1] Many of these data were obtained from Morrison (1948).
[2] Leme de Rocha (1950).
[3] Nelson and Palmer (1942).



Courtesy of U.S. Dept. Agr.

FIG. 42. DISTRIBUTION OF THE WORLD'S MILLET PRODUCTION

seed production is intended and the larger amounts are suitable for forage planting.

In spite of its unpopularity as food, millet has a nutritive value comparable to that of other cereals. The "average composition" of several grains including millet is shown in Table 33. It can be seen that both proso and foxtail millet are somewhat higher in protein than rice, sorghum, corn, and oats. However, the biological value of the protein for humans has apparently not been determined. Millet has a high percentage of indigestible fiber because the seeds are inclosed in hulls which are not removed by ordinary processing methods. It is a good source of thiamin, and probably contains appreciable amounts of the other B vitamins. Similar varieties of millet grown in different parts of the world do not seem to vary greatly in composition (Anon. 1937, Wu 1928, and Morrison 1948).

WILD RICE

Wild rice (*Zizania aquatica*) is botanically rather far removed from true rice, though both are classified in the tribe Oryzeae. In appearance the plant does not greatly resemble rice, and the grain itself has few similarities with its cultivated namesake. Evidently the aquatic habit of wild rice led to its name. The plant is also called Tuscarora rice or Indian rice.

Zizania aquatica is an annual grass, usually 5 to 10 feet tall, which bears 4 to 6 leaves 1 to 4 cm. in width and up to 65 cm. long. The panicles are usually 30 to 50 cm. long and the branches 15 to 20 cm. long. The seeds are covered with palea and lemma when they fall from the panicle. Upon removing the palea and lemma, the black kernel is revealed to have the shape of a cylinder with rounded ends. The kernel is about 10 to 20 mm. long and 0.5 to 1.0 mm. in diameter (Anon. 1948).

Wild rice is found on mud flats almost all over the eastern half of the United States and in Southern Canada eastward of Lake Winnipeg. Related species are cultivated in various other portions of the world. Minnesota is the largest producer of wild rice, and Wisconsin is second. The harvest in Canada is usually considerably less than in the United States. Probably the total value of all rice entering commercial channels in the Western hemisphere amounts to less than two million dollars annually.

It is said that seeds of wild rice are sometimes planted in marshes and on grain preserves, but the stands which are of the greatest economic importance have become established spontaneously. Except in cases where heavy attacks by parasites occur, ample re-seeding occurs to keep the wild beds established year after year, even when the bulk of the grain

is harvested. The grains, inclosed by the palea and lemma, become detached from the parent inflorescence in late autumn and fall into the water. Eventually the grain sinks into the muddy bottom and remains in a dormant condition throughout the winter (Brown and Scofield 1903).

The time of germination depends upon the water temperature and may vary in different localities from the latter part of March to the beginning of June. About a month after germination, the stalk rises above the water. Shortly thereafter, the panicles appear and the plants begin to flower. The stalks continue to grow until the grains are almost mature.

As a rule, wild rice must be harvested during the first two weeks of September or else most of the grain will fall into the water and be lost. The ripening process is not simultaneous for all grains in a panicle and the mature kernels are easily dislodged and lost in the water, so several harvests are necessary if the greatest yield is to be obtained from a rice bed.

Wild rice is harvested by Indians, mostly by members of the Chippewa tribe. Canoes, and flat-bottomed boats, manned usually by two people, are used for gathering the grain (Stevens 1952). The boats are poled through the rice beds by one of the occupants while the other draws the ripe heads of grain over the side of the boat with a stick. When the panicle is in position, it is struck sharply with another stick, dislodging the grain into the boat. Perhaps a bushel (30 to 60 lbs.) of wild rice can be gathered in an hour by this method. Large scale mechanical harvesters have also been put into use in one or two areas, but the unfavorable condition of the terrain over which they must operate greatly hampers their use. Furthermore, mechanical harvesting has been banned by law in Minnesota since 1939.

After harvesting, the grain is dried for 2 to 3 days in the open air and then it is parched and the hulls removed by pounding. Data on the changes in moisture content during drying and parching do not seem to be available although the marketed product frequently contains 7 to 10 per cent moisture. Parching is often done with crude equipment, frequently a makeshift container supported over a wood fire. Large processers pass the grain through rotating cylinders (engine-driven) situated over heating units. Control of the processing times and temperatures is a skill dependent upon the accurate judging of the texture and color of the product. Excessive heat causes popping of the rice.

After parching, the hulls of the wild rice are removed by subjecting the grain to impact. Formerly, the Indians did this by stamping on the grain, but mechanical devices are used now. A common type of apparatus consists of cylinders with rotating cores of rubber-covered spokes. Suction devices draw off the hulls as they are loosened. The kernels then

Courtesy of U.S. Dept. Agr.

FIG. 43. A, ZIZANIA AQUATICA VAR. INTERIOR PLANT, × 1/2; PISTILLATE SPIKELET, × 2; SECOND VIEW, × 5. IOWA). B, Z. AQUATICA. PISTILLATE SPIKELET, × 5. (HITCHCOCK, VA.)

pass over screens which remove broken grain and the pieces of hulls.

The wild rice of commerce is strictly a gourmet food. It is by far the most expensive cereal on the market, usually selling for over $3.00 per pound. In American cuisine, wild rice is used principally in combination with poultry and game birds, either as a stuffing or as a side dish. In such a context, discussion of the nutritive value of a food is rather academic since it is hardly likely that it will ever make up a significant part of anyone's diet. However, a comparison of the composition of wild rice with that of other cereals is included in Table 33 (p. 180) for the sake of completeness. Vitamin content of wild rice is of the same order as that of whole wheat in most respects, except that the former cereal contains considerably more vitamin B_2. Wild rice is a fair source of calcium and phosphorus (Nelson and Palmer 1942).

INDIAN RICE GRASS

Indian rice grass (*Oryzopsis hymenoides*) is a perennial which grows wild in many of the states of the western United States. Figure 44 gives an indication of the appearance of the plant. It has been described as a densely tufted bunchgrass growing from 1 to 2 feet tall. The leaves are slender and almost as long as the stems. The spreading panicle bears long pediceled spikelets and lemmas with silky hairs.

Seed formation, when it occurs, results in the formation of seeds resembling millet. They are short and almost round in contour; they are dark, approaching black in color; and are covered profusely with white hairs. The seed bears a short awn.

The grain was frequently gathered by the Indians for use in much the same manner as they used wild rice (Anon. 1948). They were parched, or ground into meal and flour for making unleavened bread. Rice grass is now used almost exclusively for forage, and it is rather highly regarded for this purpose in areas where extensive stands of the native plant occur. Bohmont and Lang (1957) reported variations in the morphological characteristics and the palatability to animals of some geographic strains of rice grass. It has been recommended for range re-seeding (Verner 1956), but apparently is not widely utilized in this connection at the present time. It competes well on dry sandy soils and may be the predominant plant in sand dune areas. As might be expected from this distribution, it is tolerant to drought. It is also relatively tolerant to high concentrations of minerals in the soil.

ADLAY

The available literature does not contain any references to the utilization or growth of adlay or Job's tears (*Coix lacryma-Jobi*) in the United

Courtesy of U.S. Dept. Agr.

FIG. 44. INDIAN-RICE GRASS

States. The plant has been grown for its ornamental properties in this country, but it is no longer very popular for this purpose. It has been used for food in the Orient for thousands of years and a variety selected for high protein content was introduced into Brazil some years ago. Several plantations now exist in the Sao Paulo area of Brazil (von Schaafhausen 1952).

The plant is a robust branched grass. Most varieties are 4 to 6 feet tall, though some are shorter. Fig. 45 gives an indication of the appearance of the plant. The inflorescences are made up in part of hard, hollow, bead-like structures which are globular or somewhat pear-shaped. The inflorescence, one of which develops at the end of each peduncle from a leaf sheath, exhibit a wide range of colors, from white through yellow, red, and purple to brown. *Coix* is monoecious, and the staminate spikes project from an orifice on the tips of certain of the bead-like structures, but the pistillate flowers are inclosed with only the styles projecting.

Wester (1921) studied the nutritional aspects of the many varieties of adlay grown in the Philippines. He concluded that the protein content was similar to that of wheat, but that the biological value of adlay protein was higher. The composition of adlay grain is shown in Table 33 (p. 180). Several methods of preparation of the grain were tried by Wester. He found that it could be hulled by machinery for hulling rice. The grain could also be ground and made into excellent biscuits (crackers). von Schaafhausen (1952) made bread and biscuits out of a mixture of 30 per cent adlay flour and 70 per cent wheat flour. The Chinese use the grain in soups, and in Japan it is made into a fermented beverage (Kogama and Yamato 1955). Experiments indicated that adlay meal can be substituted for wheat bran and middlings in a balanced ration for chickens. Hog feeding tests also showed good results.

Apparently one of the chief reasons why this cereal has not achieved greater popularity is that it requires a long growing season. An improved variety promoted by von Schaafhausen overcomes this difficulty and has the additional advantage of high yield. It ripens in five months or less, as opposed to about six or seven months for the other varieties. The yield is said to be greater than that of rice and in many instances greater than that of corn. It has been grown in temperate regions of Brazil as well as in tropical and subtropical countries.

In growing adlay, the soil is prepared as for other cereals. In Brazil, at least, the proper time for sowing is about the same as for corn. Sowing is done by machine in rows which are about two feet to a yard apart, depending upon the fertility of the soil. The plants germinate slowly and it is essential to keep the weeds under control during the first month.

Courtesy of U.S. Dept. Agr.

FIG. 45. ADLAY OR JOB'S TEARS

Harvesting has been done by hand in most of the plantations, but it is said that the seed can be mechanically harvested by methods used for barley.

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SECTION II

Processing Methods

Robert A. Larsen

Milling

INTRODUCTION

The milling of cereal grains into a powdery material and the production of food products from this powder appears to be as old as recorded civilization. Many authors, having an interest in the history of foods, have treated this subject in detail. That is not our purpose. What is of particular interest is that this practice has withstood the test of time and has been passed from generation to generation to the present day.

No doubt the taste of products made from cereal grains has much to do with this fact. However, when one remembers the wide variety of products made from ground cereals varying from the unleavened flat bread—such as the chapaties (Nath, Singh and Nath 1957) of India—to the yeast leavened, highly specialized bread products of the western civilization, it becomes apparent that this is not the entire story. Perhaps the primary and compelling reasons for the continued use of cereal grains as a food is not their taste but rather the ease of growing them and their storage stability. Man early learned the power of dehydration as a method of preserving cereal grains. Apparently, through the teachings of trial and error, civilization discovered that, by sun drying cereals, the seeds of these grasses could be stored for many months without spoilage (Oxley 1948).

It is also a fact that man very early learned to grind grain into a powdery material before eating it. This step was important because it greatly increased the variety of foods which could be made from cereals. It appears that the first foods were flour and water pastes—the art of leavening foods being more recent. Many unleavened cereal foods, however, are still used—pie crusts and alimentary pastes (macaroni and spaghetti) being examples.

It is believed that the Egyptians were the first to ferment doughs with yeast (Thorpe 1927) to produce bread. Yeast fermentation to make bread remains to this day a cornerstone of the baking industry in a large part of the world.

Chemically leavened products did not appear until the nineteenth century (Anon. 1940). Corn flours and corn meals in the United States have particularly benefited by the development of chemical leavening.

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The results of this heritage are that the production of flours from cereals is today in very large tonnages. While a great deal of milling is still done by hand and more by millstones, the major production in most countries is in large, highly mechanized mills. It is this type of production which will be considered here.

THE MILLING OF WHEAT

Introduction

There are a number of good books written on wheat milling. For more detailed information on a specific subject, the reader is referred to the following: Kozmin (1917), Scott (1951), Smith (1944), and Lockwood (1952).

The wheat milling process consists of five main parts. They are:

1. The reception and storage of the wheat.
2. The cleaning of the wheat.
3. Tempering or conditioning.
4. The milling of wheat into flour and into its by-products.
5. The storage of the finished product.

It should be remembered that the milling of wheat is a physical process. The miller is confronted with a seed composed of a bran coat which protects the seed from the elements, an embryo called the germ and a starchy food reserve area called the endosperm. This composition applies to all classes of cereal seeds and thus all are susceptible in some degree to dry milling techniques.

TABLE 34

THE COMPOSITION OF CEREAL SEEDS

	Wheat	Rye	Corn	Durum
Bran	12	10	6	9
Germ	3	3	12	2
Endosperm	85	87	82	89

The problem in each case is to make flour or a granular product. This is done by separating the endosperm from the bran and the germ since it is pulverized endosperm that is transformed into flour goods.

The preparation of flour does not consist simply of grinding the berry and removing the flour from the germ or bran by some appropriate separation technique. If this were done, a flour similar to whole wheat flour would be made instead of a white flour. To make white flour, it is necessary to remove substantially all of the bran and germ.

The germ can be rather easily removed because it contains oil which

makes it putty-like. Hence, it will flatten rather than pulverize under the force of rolls. The resultant large, flat germ pieces can then be removed by sieves.

The case with bran is quite different. Bran, like endosperm, grinds very easily into a fine powder. When bran is in this form, it is quite impossible to separate it from the powdery endosperm (Lockwood 1952). Flour contaminated with wheat bran is brownish rather than white and is not as desirable for food purposes.

Thus, the aim of the flour milling system is to obtain as much flour as is possible from the endosperm without contaminating the flour with bran particles or with germ. Since most mills obtain about a 70 per cent yield of flour from a theoretical yield of about 85 per cent total endosperm, they are operating at about 80 per cent maximum efficiency. Clearly, there is room for improvement.

The effective separation of bran from endosperm depends upon two principles. Both are related to the construction of the wheat berry. The first is the fact that, when wheat is soaked with water, the bran becomes tough and rubbery while the endosperm, which is in the interior, becomes soft and friable. This soaking step is called tempering or conditioning.

The second fact that makes the separation of bran and endosperm possible relates to morphological structure in that, when the wheat berry is sheared by the corrugations of the first roll or break, it will split open releasing some endosperm and flour. Most of the particles will resemble partially flattened clam shell pieces. As a result, the remaining endosperm of the wheat berry is exposed.

Thereafter, the milling process involves the careful scraping of this endosperm away from the toughened bran so as not to contaminate it with the bran. As already stated, if all of the endosperm could be separated from the bran, about an 85 per cent yield of flour would result.

The 15 per cent of flour not recovered as such is found in the by-products of milling. This flour finds its way partly into a product called shorts. Shorts are essentially pieces of finely ground bran and adherent and free endosperm mixed together. Shorts are sold mainly for animal feed with a smaller portion going into food and into industrial uses. The remainder of the flour still clings to the large bran.

The by-products of milling—the germ, the shorts and the bran—together comprise about 30 per cent of the mill streams. About one-half of this amount is bran and about one-half shorts. A very minor amount is germ—about 2.5 per cent of the total wheat berry.

Collectively, these by-products of milling are known as millfeed and are sold as such. This name is derived from the fact that the first uses of the by-products were in the animal feeding area. This is still true.

Turbomilling

Recently Wichser (1958), Gellrich (1958), Elias (1958), and Elias and Scott (1957) reported a new development which has been added to the flour milling process, an innovation which is bringing about some striking changes in the products that can be produced by a mill. This process is called **turbomilling.**

In principle, this process involves the air classification of flour to separate the protein and starch, one from the other. Separation of starch from protein by air classification of flour is only possible because of the peculiar structure of the endosperm portion of wheat.

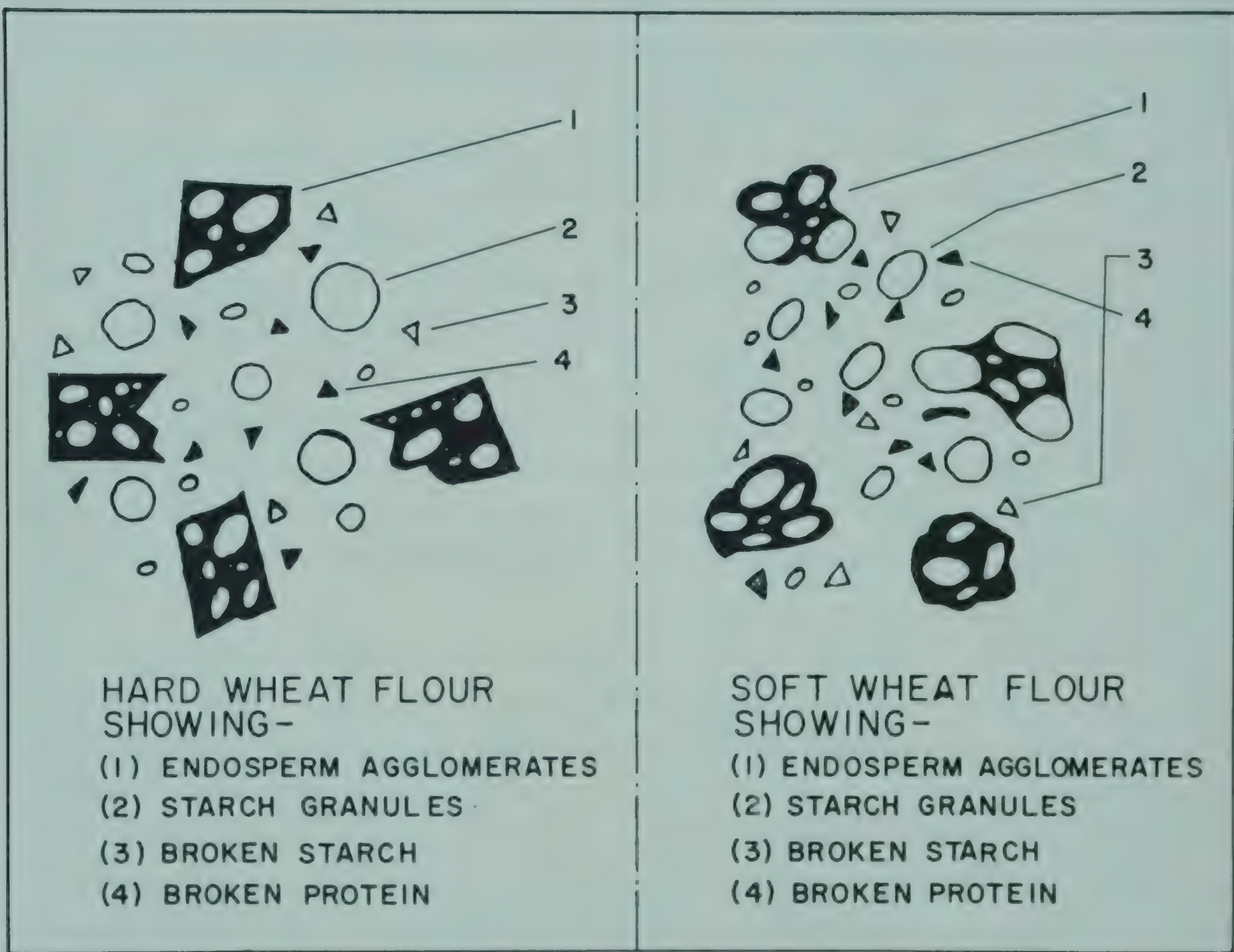


FIG. 46. PARTICLE TYPES PRESENT IN SOFT WHEAT AND HARD WHEAT FLOUR

Endosperm, when observed under the microscope, is a series of plant cells, the walls of which are composed of cellulose. Actually, this cellulose wall is so thin as to be almost invisible. The contents of the cells are more easily seen, particularly the starch and the protein constituents. The starch appears as small, round objects varying in size from 5 to 50 microns. By certain methods, it can be shown that between these starch granules lies protein. This latter fact was first published in the works of Hess (1953 and 1954).

Since this protein lies in the interstices between the starch, particularly where three starch particles come together, its shape is not round but rather it is in the shape of a wedge.

During the milling of flour, the endosperm cells are broken apart. Upon further milling of the endosperm pieces, some of the starch and protein are separated, one from another, as discrete pieces; the protein chunks are irregular in shape and small in size (mostly below 20 microns), while the starch pieces are round and usually larger.

Thus, flour produced in a normal roller mill contains three distinct physical entities. These are the endosperm chunks, the starch granules and the protein particles.

The flow-dynamics properties, (size, shape and specific gravity) of the different particles permit separating into size ranges where protein matter is enhanced or depleted in the material. For example, a vortex classifier uses centrifugal force in an air medium to attain flow-dynamic size separations.

As a consequence, flours rich in protein (above 20 per cent) and flours low in protein (below six per cent) are beginning to appear on the market. At least one literature citation claims it possible to make wheat starch by this process (Wichser 1958).

Since turbomilling is new, the limits of its possibilities are not known. The ultimate would be a separation of flour into pure starch and protein. If this is accomplished, many new market possibilities for cereal products will undoubtedly be established.

Returning to the principal divisions of the milling system, let us consider each part in order of appearance.

Reception and Storage of Wheat

Wheat selection is the backbone of the flour milling process. Without the proper wheat varieties,—dry, unsprouted and free from insect contamination—the miller is powerless to produce an adequate product.

About 70 per cent of the milling of flour in the United States is for the production of bread flour. This percentage is even higher in some of the other countries.

Whether a wheat is to be used for bread production or for cakes, cookies, pastry or biscuits depends primarily upon the protein content of the wheat. Bread flours range from 11 per cent protein on up. Cake, pastry and biscuit flours fall between 8 to 11 per cent protein. Cake flours are generally at the lower end of this protein scale and biscuit flours at the upper end. Since the flour contains a lower percentage of protein than the grain from which it is milled, the wheat is bought at about one per cent higher protein content than wanted in the finished flour.

It is up to the wheat buyer to provide the miller with the proper wheats for milling. He mainly looks for proper protein content. Improper drying in the field is detected by a musty odor which is caused by mold growth. Sprouted wheat results from damp conditions during harvest. Generally, the wheat buyer knows which areas of the country are afflicted with sprouted or tough wheat in a given year. He avoids purchases from these areas. An abnormally high maltose test (see chemical methods) also indicates sprouting conditions. Insect contamination can be detected by soft X-ray analysis of the wheat, and this method of control is now finding wide acceptance.

It should be pointed out that wheat, as other cereal grains, is subject to government inspection and grading. Such a grading system is of great help to the grain buyer since it not only takes into consideration the soundness of the wheat for milling purposes, but also limits the amount of contamination of other cereal seeds, weed seeds and foreign matter. Special grade designations are made for wheats with moisture contents in excess of 14.0 per cent or 14.5 per cent, depending on the class, thus limiting the worth of high moisture wheats.

Wheat is stored at the mill in large concrete bins. The amount of storage space at the mill varies greatly. Most all mills store at least a six weeks' supply with some mills having over 32 weeks' storage capacity.

Before storage, however, the wheat undergoes a preliminary cleaning and drying to remove the gross impurities and foreign material and to remove moisture if necessary so that the wheat can be stored without heating. Heat production results from the growth of micro-organisms in the grain and is caused by the heat of their respiration process and the fact that, in the confined space of the silo, this heat cannot escape (Anderson and Alcock 1954). To prevent this, wheat must be kept dry—normally no higher than 14.5 per cent moisture.

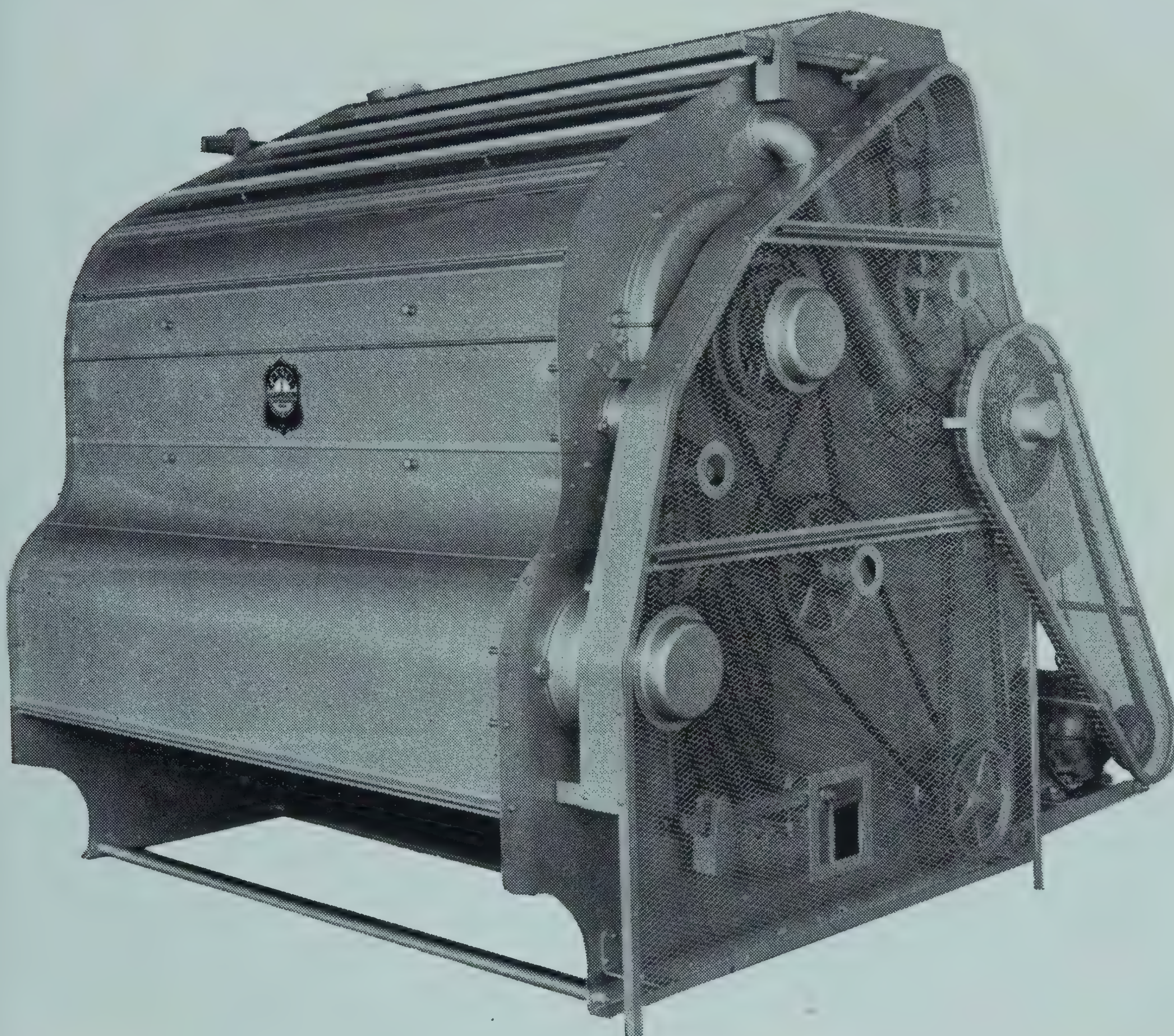
On arrival at the mill, wheat will contain foreign impurities, the extent of the contamination being less if adequate government standards and inspection exist. Some wheats contain sticks, stones, string and even bits of cloth. These must be removed before wheat goes into storage. Dust and smaller pieces of foreign matter are left to the cleaning done just prior to milling.

Therefore, after the wheat is removed from the carrier and is weighed, it goes over sieves which remove all coarse impurities by sifting. One such type is an oscillating inclined sieve. Usually air is drawn through the sieve at several points to remove lighter impurities by aspiration.

Another separator which is widely used depends upon a revolving wire mesh drum. The wheat falling on the mesh (about $^3/_8$ by $^3/_4$ inch rectangular perforations) goes through the openings and is trapped in the

center and carried away by baffles. The large rubble cannot pass the screen and is discarded.

The drying of wheat before storage has become much more important in recent years. The greater importance of wheat drying at the present time results from the tendency to store more wheat at the mill for longer times with consequently greater opportunities for heating. The second



Courtesy Simon-Carter Co.

FIG. 47. CARTER SCALPERATOR

reason is that much wheat is now harvested by a combine machine which cuts, threshes and sacks the wheat all at once. In this operation, the drying of cut wheat in shocks before threshing has been abandoned. The result is wheat of higher moisture content.

Wheat is dried by the application of heat. Both hot air and radiators are used. In either case, the evaporated moisture is carried away by air currents. Wheat cannot be heated indiscriminantly in order to drive off moisture. Excessive temperatures damage the properties of gluten for bread baking. Lockwood (1952) states that a drying section must be

large enough to "allow time for the internal moisture to diffuse at a temperature of not over 115° F. when the moisture content is over 17 per cent, and not over 130° F. when the moisture content is under 17 per cent."

Since uniform heating is desired, hot water radiators through which the grain passes are preferred to hot air; hot air tends to channel and cause hot pockets.

Normally, moisture is removed down to the last 0.5 to 1.0 per cent above the desired dryness. The evaporation of this last 0.5 to 1.0 per cent moisture is used to cool the wheat back down to room temperature.

Thus, the three stages of drying are these: The wheat is preheated to the desired temperature. Next, water is removed by heat vaporization. Finally, the grain is cooled by water evaporation. Modern wheat driers, therefore, are composed of three sections, each handling one of these tasks.

After drying, the wheat is ready for storage. Most storage facilities are built of concrete because it is cheap, easy to maintain and fire- and vermin-proof. Metal conducts heat too well, causing the grain near the wall to heat and to drive moisture into the interior of the bin. Wood is not practical for large bins.

Bins hold from 50 to 1,000 tons of grain, are up to 20 feet in diameter and 60 to 100 feet deep. A big problem in bin design is to avoid grading the wheat by weight. The heavy wheat goes to the bottom, the light to the top. This density separation can cause serious complications in milling. Grading is avoided by using distributors or baffles to divide the grain as it enters from the top of the silo or is removed from the bottom. Since, upon discharge, the wheat does not "pull down" as a solid but funnels through the center of the pile, the baffles aid in removing wheat approximately in the sequence in which it was loaded.

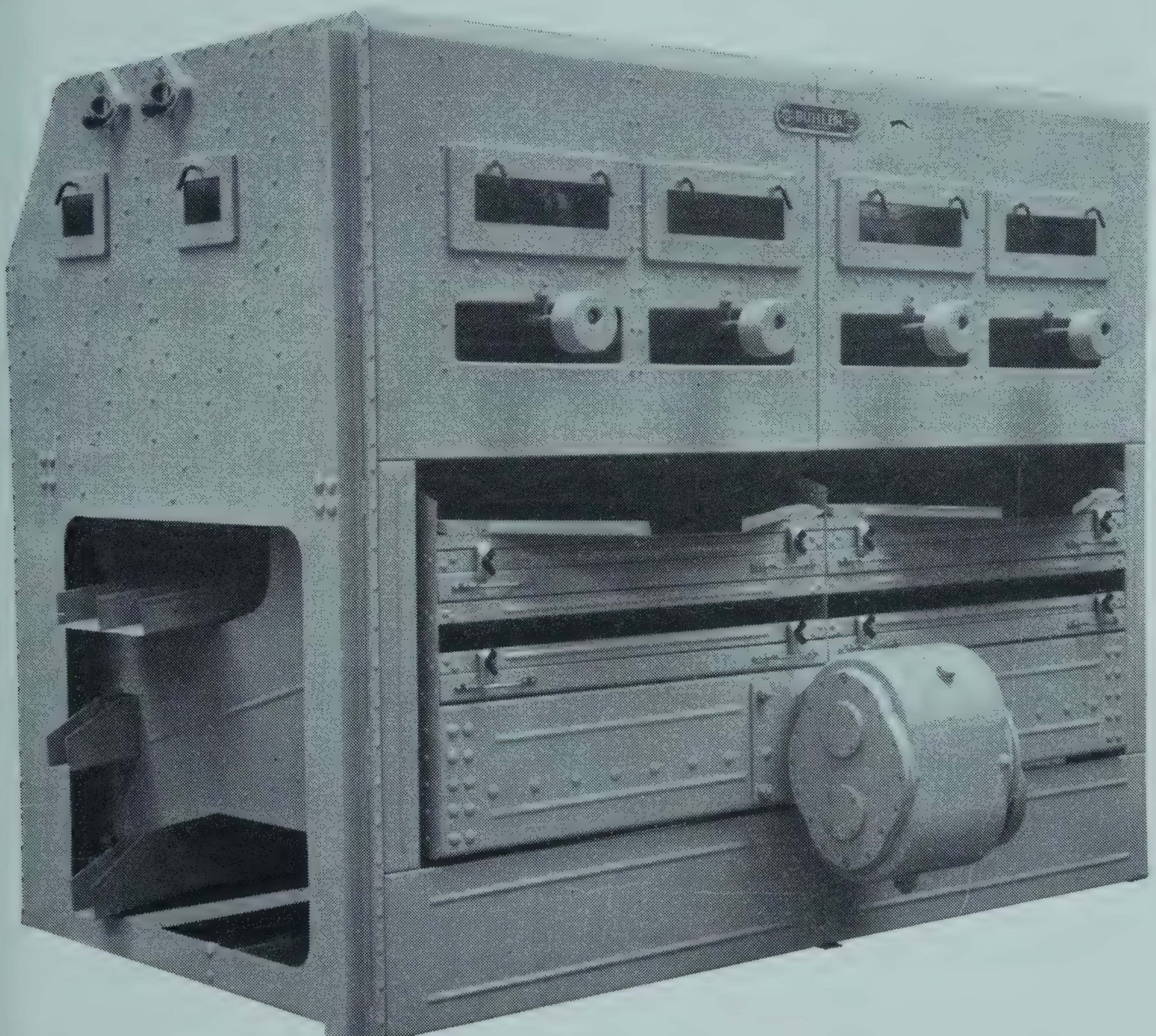
The Cleaning House

As grain is needed for milling, it is withdrawn from the storage area into the mill proper. The first step is to send the wheat through a cleaning operation prior to the actual milling. This section of a mill is called the cleaning house.

Since the gross impurities have already been removed at the storage bins, the techniques used in the cleaning house must be more refined. Whatever the machine used, however, it has but one of two purposes, either it is removing loose foreign material or it is removing dirt adhering to the surface of the grain. Normally, dirt removal from the surface of the grain is done last using friction, aspiration, and/or water-washing techniques.

Wheat is weighed as it enters the cleaning house and thereafter goes through a separator. This is the same type of separator as used in the silo operation except that it is set to remove fine impurities and dust. Small pieces of sticks, stones, sand and dust are sifted away and light impurities such as wheat chaff are removed by air currents.

The next operation involves magnetic separation to remove bits of adventitious metal which may have found its way into the wheat mix.



Courtesy Buhler Mill Engineering Co.

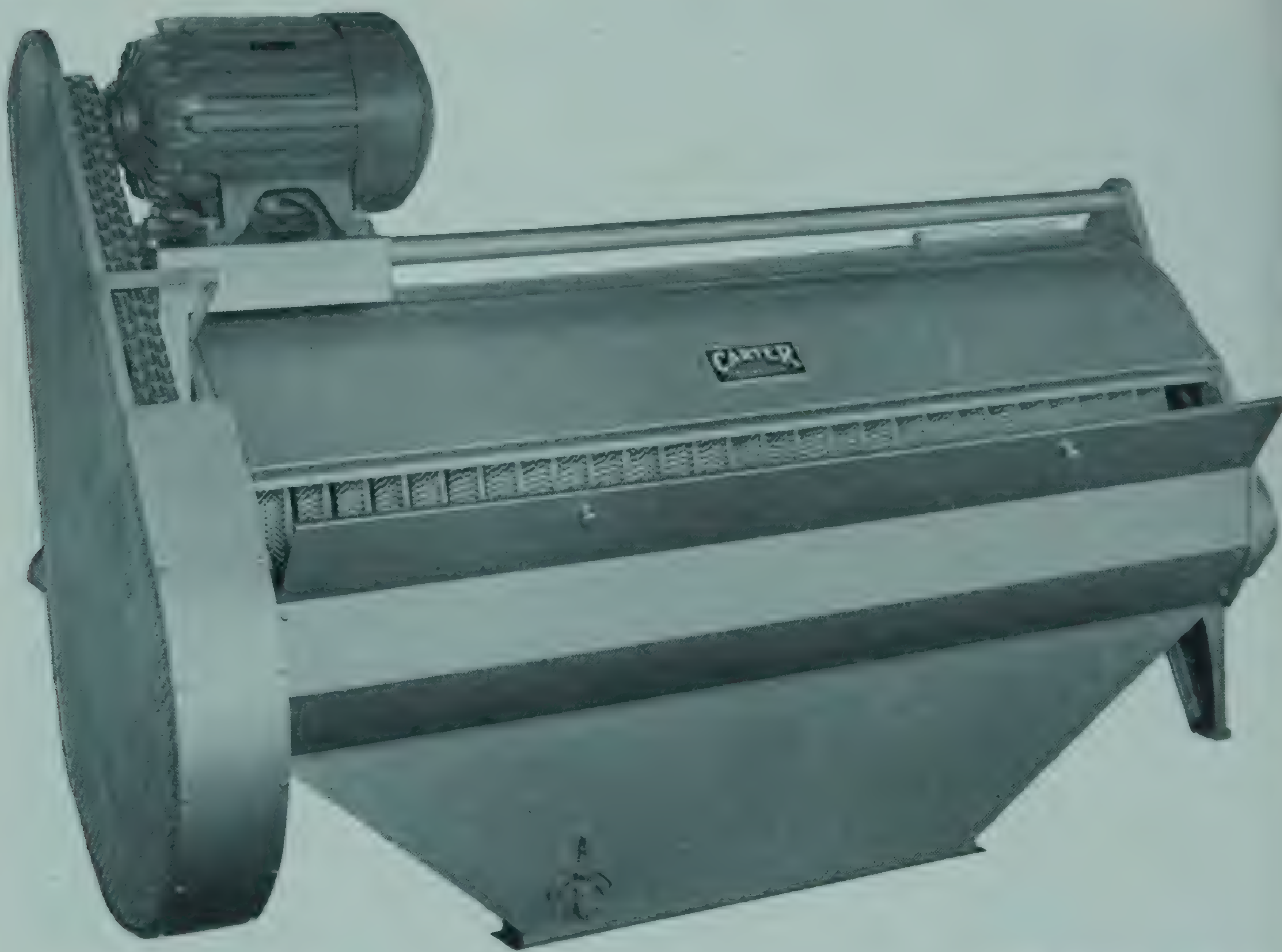
Fig. 48. An Aspirator for the Removal of Light Impurities from Wheat

Although aspiration is provided in the first sifting machine, there is usually a second aspiration and possibly more as the wheat passes through the cleaning house. No aspirator is totally efficient so in order to do an adequate job, several retreatments are necessary.

The next cleaning machine is designed to remove cereal grains other than wheat and to remove foreign seeds, particularly weed seeds. This is done by catching the unwanted seeds in specially designed pockets in

a revolving metal plate. These indentations are designed so that the weed seeds or the oats or barley fit into the pockets but not the wheat. The wheat, therefore, passes through the machine while the other seeds are lifted up and carried away.

These machines come in several designs. The most efficient, however, is the use of disks set at right angles to the flow of the wheat. The wheat flows through and out the end of the separator while the seeds caught by the disk are lifted away from the bulk.



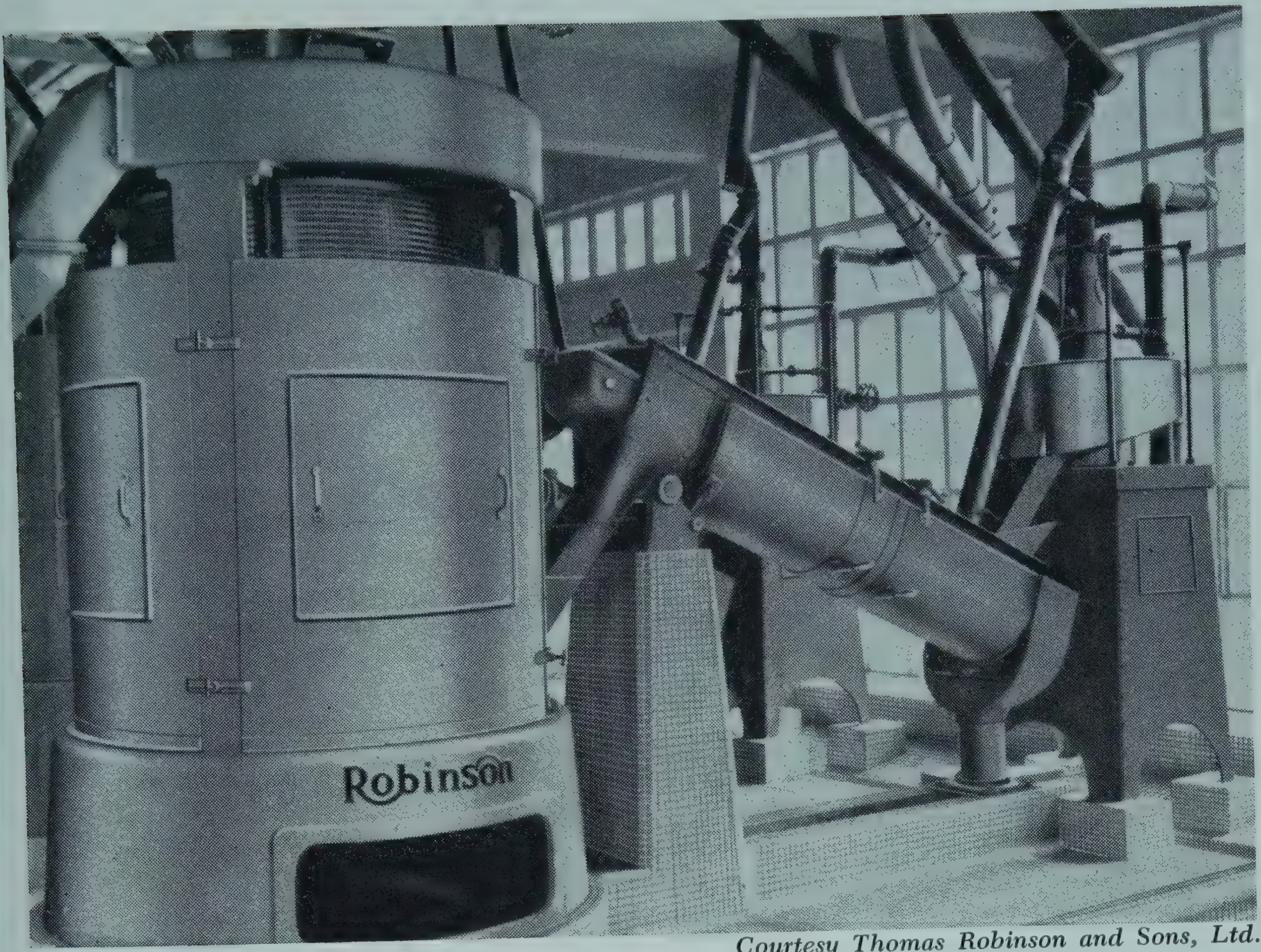
Courtesy Simon-Carter Co.

FIG. 49. A DISK SEPARATOR FOR THE REMOVAL OF UNDESIRABLE SEEDS FROM WHEAT

In such a disk separator, different types of disks can be placed to catch different seeds and the machine can be set to discharge the wheat at any point along the route.

Scouring involves the removal of dirt on the surface of the wheat by friction. The scourers differ widely in design. Usually, the wheat is moved by paddles against an emery-coated surface, the severity of the treatment being controlled by the clearance between the paddles and the stationary emery surface.

The dirt and beeswing (the outer coating of the wheat bran) are removed by air aspiration.



Courtesy Thomas Robinson and Sons, Ltd.

FIG. 50. A WHEAT WASHER

In some cases, a light washing is performed before the wheat enters the scouring machine in order to toughen the wheat so that it does not break during the mechanical agitation.

A brushing operation also is used to remove the remaining dust. This final polishing removes loose branny particles which are then aspirated away.

The final cleaning step is a water wash. The water dissolves the dirt and permits stones and bits of metal to sink. In some cases, it appears to reduce microbiological contamination of the wheat, and in all cases the washer tends to add about one per cent water to the original moisture content of the wheat.

There are numerous types of washers. Usually, the wheat is conveyed through a trough of water where dirt is floated away and the stones sink. This operation is particularly effective in removing dirt from the crease of wheat, dirt that is missed by dry scouring. Following the washing, excess moisture on the surface of the wheat is removed by centrifugal forces.

Tempering (Conditioning)

Tempering, as the word is used in the United States, refers to the addition of water to the bran and endosperm. The bran becomes tough and

rubbery while the endosperm becomes less vitreous. This improves milling efficiency.

In European circles, the concept of tempering is broadened to include not only the toughening of bran but also the changing of the physical and chemical characteristics of the endosperm during milling. This broader concept of tempering is called conditioning (Gehle 1952). To do this, a controlled heating process is employed in addition to the moistening procedure.

Wheats can be broadly classified into two classes depending on their milling characteristics. One is hard wheat and the other is soft wheat. It is estimated that it takes about 20 per cent more horsepower to grind a hard wheat to a given particle size than a soft wheat.

When hard wheats and soft wheats are found in the same wheat mix—and this is quite common, particularly in European countries—the miller is confronted with a difficult problem. Shall he set the rolls close and overgrind the soft wheat, or shall he set them wide and undergrind the hard wheat? Obviously, neither alternative is desirable. Fortunately, conditioning provides a partial answer.

If hard wheats are maintained in the presence of moisture under the proper conditions and for appropriate periods of time, the endosperm chunks become softer. In other words, they grind more like soft wheats. This is because the water is allowed to penetrate the endosperm to cause it to become more mellow. By this technique, the milling problems of hard and soft wheat mixtures are considerably simplified.

Until the advent of the more modern systems, tempering—as it is still practiced in the United States—involved the addition of water to grain to raise the moisture to 15 to 19 per cent for hard wheats and 14.5 to 17 per cent for soft wheats and allowing the wheat to lie in tempering bins (with little or no temperature control) for periods of 18 up to 72 hours. During this time, the water enters the bran surface and diffuses inward. This process causes the bran to lose its friable characteristic and to become leathery in texture.

Usually, tempering is done in successive steps since it is difficult to add more than a few per cent water at one time.

Conditioning, in contrast to tempering, always involves the use of heat since quick diffusion of water into the endosperm as well as the bran is desired.

It has been established that water enters the endosperm through the germ end of the grain and also through breaks in the bran coat (Sugden 1956). If properly controlled, the bran is toughened, the endosperm separates more easily from the bran and can be ground to a powder with less horsepower requirement.

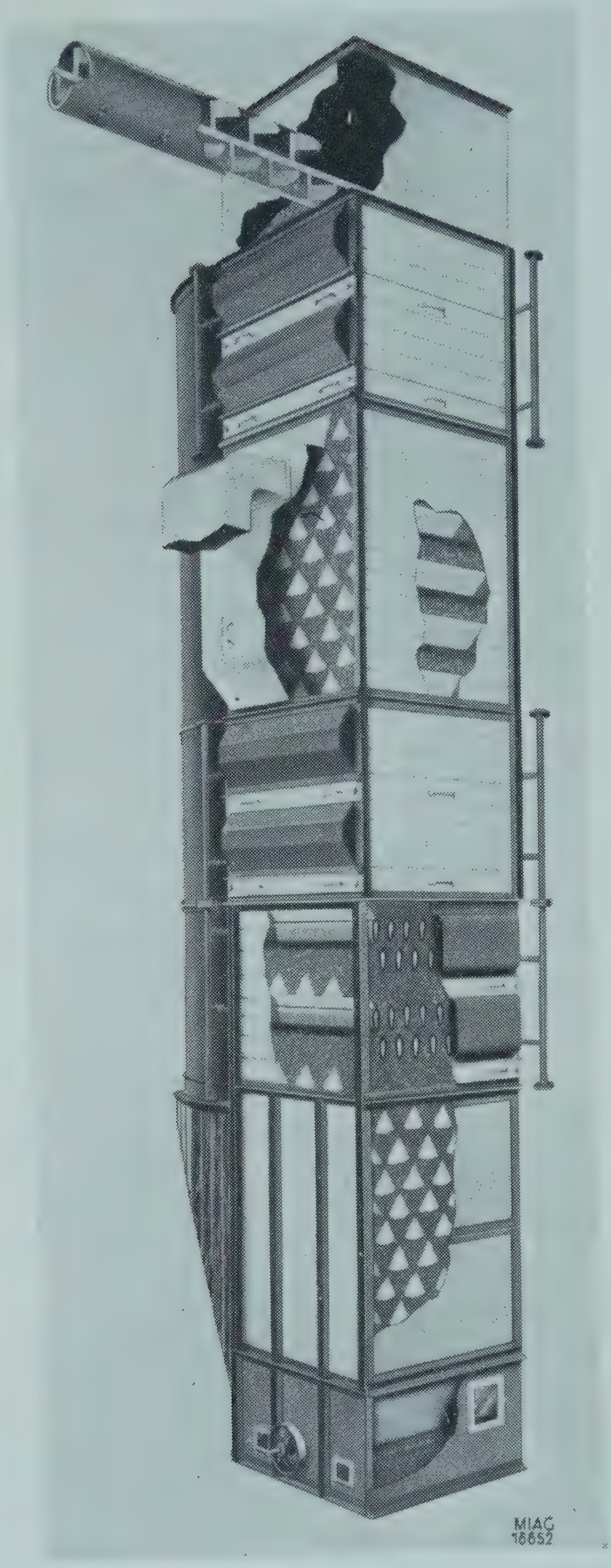


Fig. 51. A Three-Stage Wheat Conditioner

Courtesy of Miag-Nortamerica

Since heat affects gluten quality, its application must be controlled. Normally, a temperature of 115°F. cannot be exceeded without causing detectable changes in the baking quality of the flour.

Under some conditions, this temperature limit is deliberately exceeded in order to change the protein. Higher temperatures cause the gluten to become more resistant to extension and to break more easily during the extension (Kent-Jones and Amos 1957). Normally, gluten treatment during conditioning involves temperatures between 115°F. and 180°F.

The drier the wheat, the higher the temperature used and the longer the time required.

Some conditioners involve four sections. The first section heats the wheat to the proper temperature. The second section adds moisture and holds the wheat for the proper time. The third section cools the wheat to room temperature and the final section provides a holding bin where the moisture in the wheat is allowed to equilibrate before milling. Conditioners are sold as the first three units while the holding bin is separate. However, all four parts must be considered if one is planning such an installation.

In addition to being able to mellow endosperm, conditioners save much time compared to tempering. All of the conditioning water can be added at once. The wheat goes through the preheat section, the water addition section, and the cooling section in one and one-half hours or less. Millers differ as to the time the wheat is held in the holding bins. Figures from 8 to 18 hours are quoted with the longer times being used for the harder wheats.

The construction of conditioners is much like that of driers and indeed the same device serves a dual purpose in some instances. Radiators rather than hot air are the preferred method of heating. Cooling is done by allowing water evaporation from the surface of the wheat or by the application of cold air.

In one case (Simon of England), the wheat is heated very rapidly by direct injection of steam and held at temperatures of 120° to 150°F. for about one minute. Following this, there is a rapid cooling by plunging into cold water and thence to a centrifugal machine to remove the surface water.

This method of conditioning is extremely fast and has the advantage that the cooling process, since it is not done by cool air or evaporation, does not tend to dry the bran coat. It is claimed, also, that an actual rupture of bran coat and endosperm occur which enhances the milling process.

The Grinding of Wheat

The milling of wheat is done on rolls. The roller milling system is divided into two sections. In the first, the bran is broken open and the endosperm milled away in successive and gradual steps. This system quite often involves four or more sets of rolls, each taking stock from the preceding one. In other words, they are connected in series, not parallel. This system, since it cracks open the bran, is called the break system, and the break rolls are classified as first, second and so on.

After each break, the mixture of free bran, free endosperm, free germ

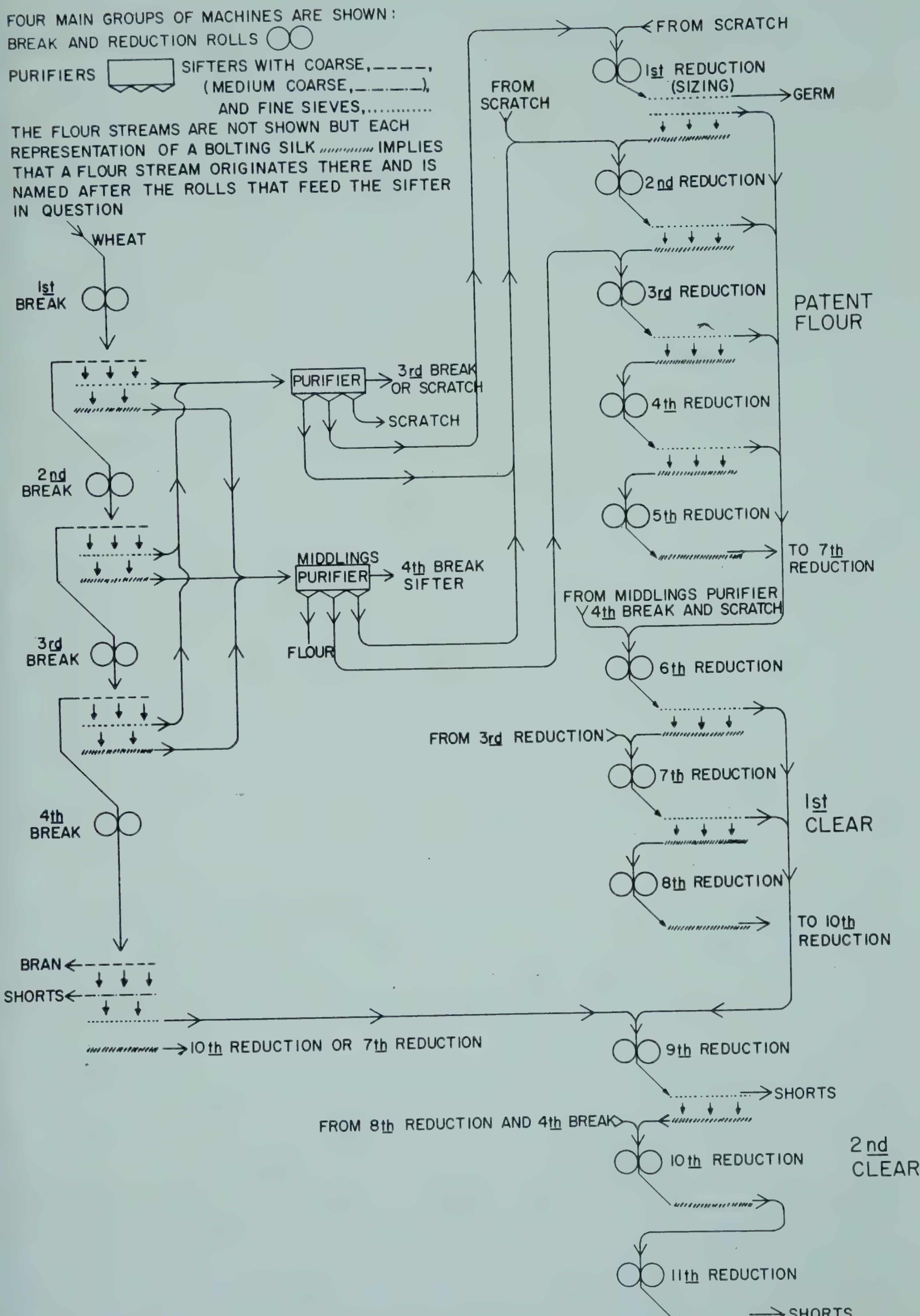


Fig. 52. A Simplified Wheat Milling System

and bran still having adhering endosperm are sifted. This sifting system is called the scalping system. The bran having endosperm still on it goes to the next break roll and the freed endosperm is sent to the reduction rolls where it is further reduced to the proper particle size for flours.

Rolls in the second system are the reduction rolls just mentioned. They are similar to the break rolls except that their surface is normally smooth rather than corrugated. After each reduction of endosperm, the flour is sifted away from the unground endosperm chunks (called middlings after their middle size as contrasted with the larger endosperm chunks that come from the break system). The middlings are returned to the second roll and the process repeated. Many mills have as much as 13 reduction rolls in series and number them as such.

This does not mean that flour passes through twelve reduction roll systems. The endosperm from the first break may go through five reductions before all is reduced to flour size. The endosperm from the second break may pass through 4 reductions, the third through 3 and the fourth through 2. It isn't profitable to handle the flour from the later breaks through much further processing. This is because the third and fourth breaks are near the bran layer when they are scraping flour from it and thus the floor is contaminated with branny material. As already discussed, such flour is of low grade and much of it is passed into millfeed.

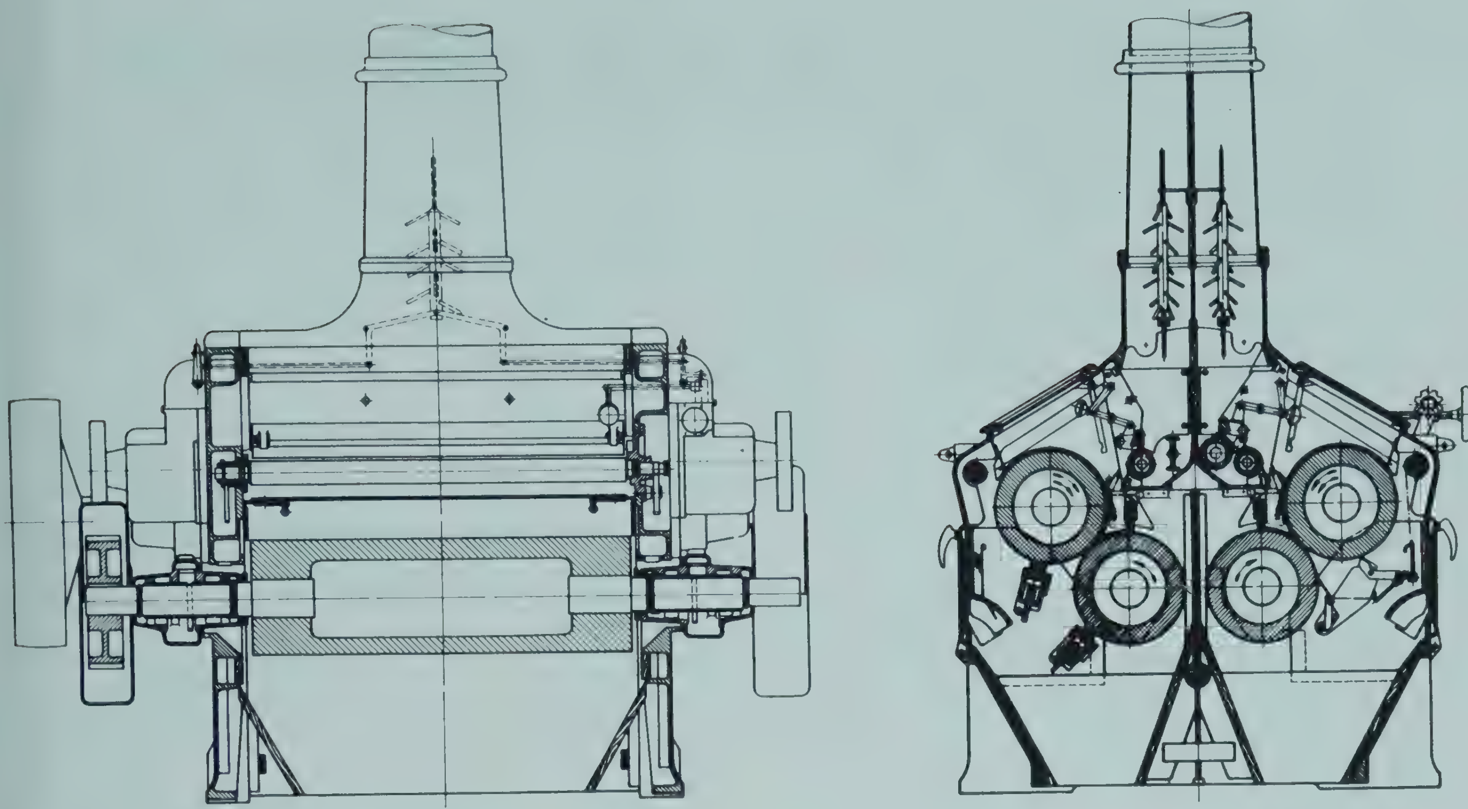
The art of milling lies in the system that the miller actually uses to mill his flour. Each mill is different, and some operate to obtain yields of 2 and 3 per cent more flour than the average. This percentage can mean the difference between profit and loss.

The Break Rolls

The crushing power of a roller mill depends upon shear as well as pressure forces. One roll of a pair revolves faster than the other. This differential in speed for break rolls is $2^1/_2$ to 1. The faster roll runs at from 280 to 450 r.p.m.; the slower speeds being preferred in European mills.

Break rolls are always fluted to obtain the necessary grinding effect. These saw-toothed flutes run spirally around the roll and the number of flutes per inch increase from the first to the fourth break. The first break runs 10 to 12 flutes to the inch, the fourth about 28 flutes.

In Europe, the rolls are not set horizontally as in the United States but rather on a diagonal. Each design has an advantage. The diagonal rolls allow more machines in a given amount of floor space but the horizontal rolls permit more uniform feeding of grain to the rolls and thus allow faster roll speeds and more production per roll. The choice of horizontal or diagonal rolls seems to be mostly a matter of preference.



Courtesy of Miag-Nortamerica

Fig. 53. Diagram of a Roller Mill

The Break Sifting System

As already explained, after each break bran, endosperm and germ are separated one from another. Normally, all germ is removed by the third break to avoid contamination of flour with germ. Germ contains substances which are very deleterious to bread baking (Sullivan *et al.* 1936). Early removal of germ is necessary before the germ is ground fine and cannot be separated.

The first device in the break roll sifting system (called the scalping system) is a sieving device. This may take several forms, but the plansifter is most important and most prominent.

As the name implies, a plansifter has flat sieves piled in planes, one above the other. The action of the sifter is rotary in a plane parallel with the floor. As the sifter moves in about a $3^1/_2$ inch circle, the flour spills through to the sieve below while the others are spouted away.

As many as twelve sieves are piled on top of each other and four separate compartments are found in one plansifter. Per unit of floor area, plansifters have tremendous capacity, and this accounts for their prevalence.

Plansifters in a scalping system remove at the top large pieces of bran with adhering endosperm. These are returned to the next break. The next sieves are finer and remove bran and germ. The next layers, finer yet, remove endosperm middlings and the bottom throughs are flour. Wire mesh screens are used for the coarser separations and cloth for the finer separations. The finest sieves which pass flour are very fine indeed. They run up to 196 mesh per inch and have openings, for example, of 0.06 mm.

The middlings go through further cleaning to remove fine bran particles before they are ground to flour on the reduction rolls. Purifiers are used for this purpose.

A purifier is essentially a long oscillating sieve inclined downward from head to tail. The sieve becomes coarser as it progresses towards the tail.

Passing up through the sieves in the direction of from floor to ceiling are air currents. These air currents passing through the mass of material flowing down the sieve exert a lifting effect. This causes the flour particles to stratify depending upon their size, density and shape. The stock separates into layers. On the bottom are the smallest pure middlings. Next are the larger middlings. Next come small endosperm and bran particles. Next, the large pieces of endosperm still adhering to bran, and endosperm chunks. On top of these are the heavier bran particles and finally the light bran particles.

The sieves are so designed that only the endosperm particles pass through. These go on to the reduction rolls. The overtails are the composite particles of bran and endosperm and pure bran. These go to millfeed or back to a break roll. The aspirated materials are carried to the millfeed.

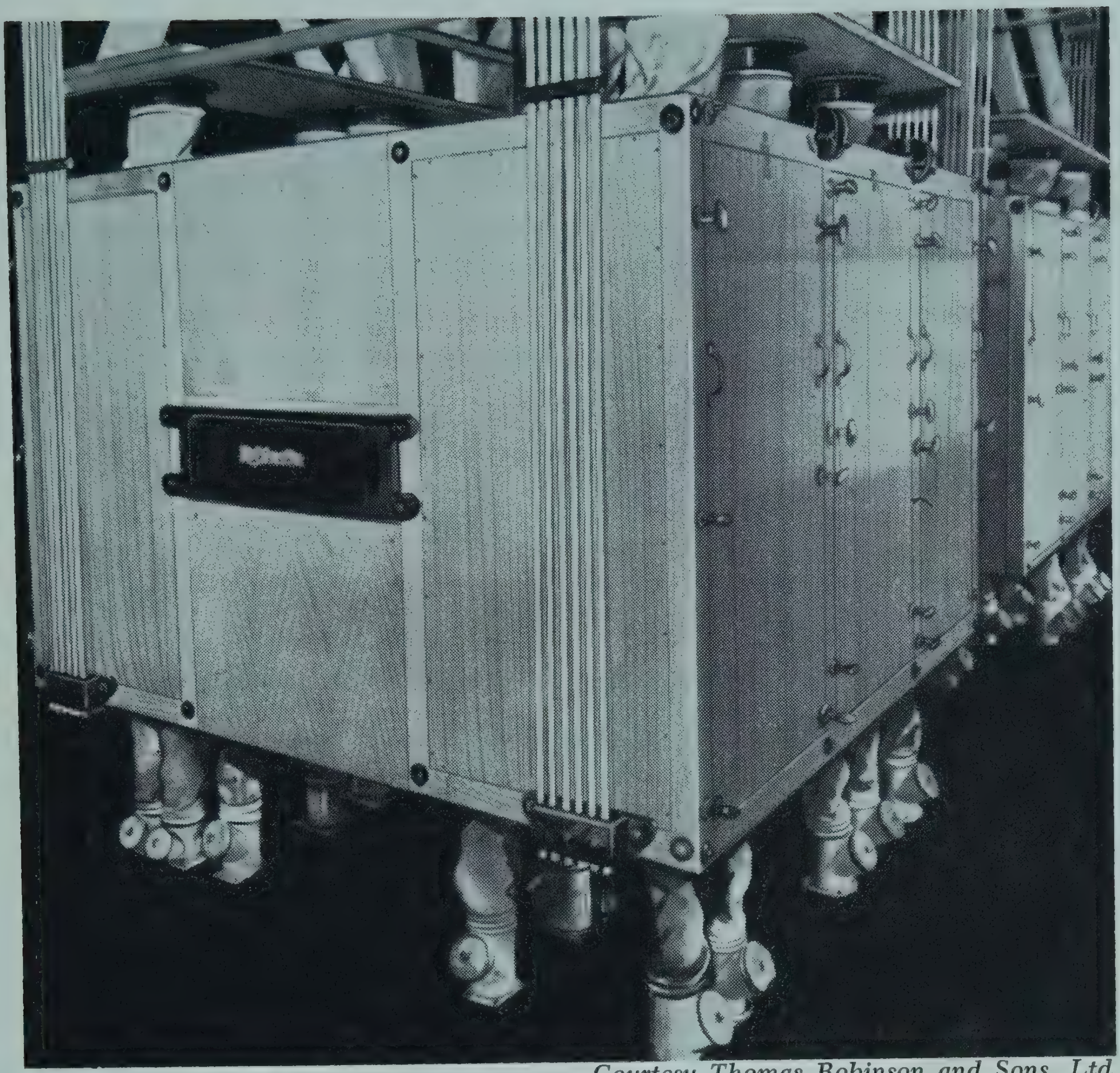
The advantage of a purifier is that it performs separations that are impossible on sieves. It was the development of the purifier that made the transition of mills from stones to steel rolls a practicality. Not until the advent of the purifiers were really high-grade flours easily produced.

As many as twelve purifiers are quite normally found for four break rolls in the scalping system. For example, the fine middlings from the first, second, third and fourth breaks normally go through a double purification step while the coarser middlings need only one purification treatment.

The Reduction Rolls

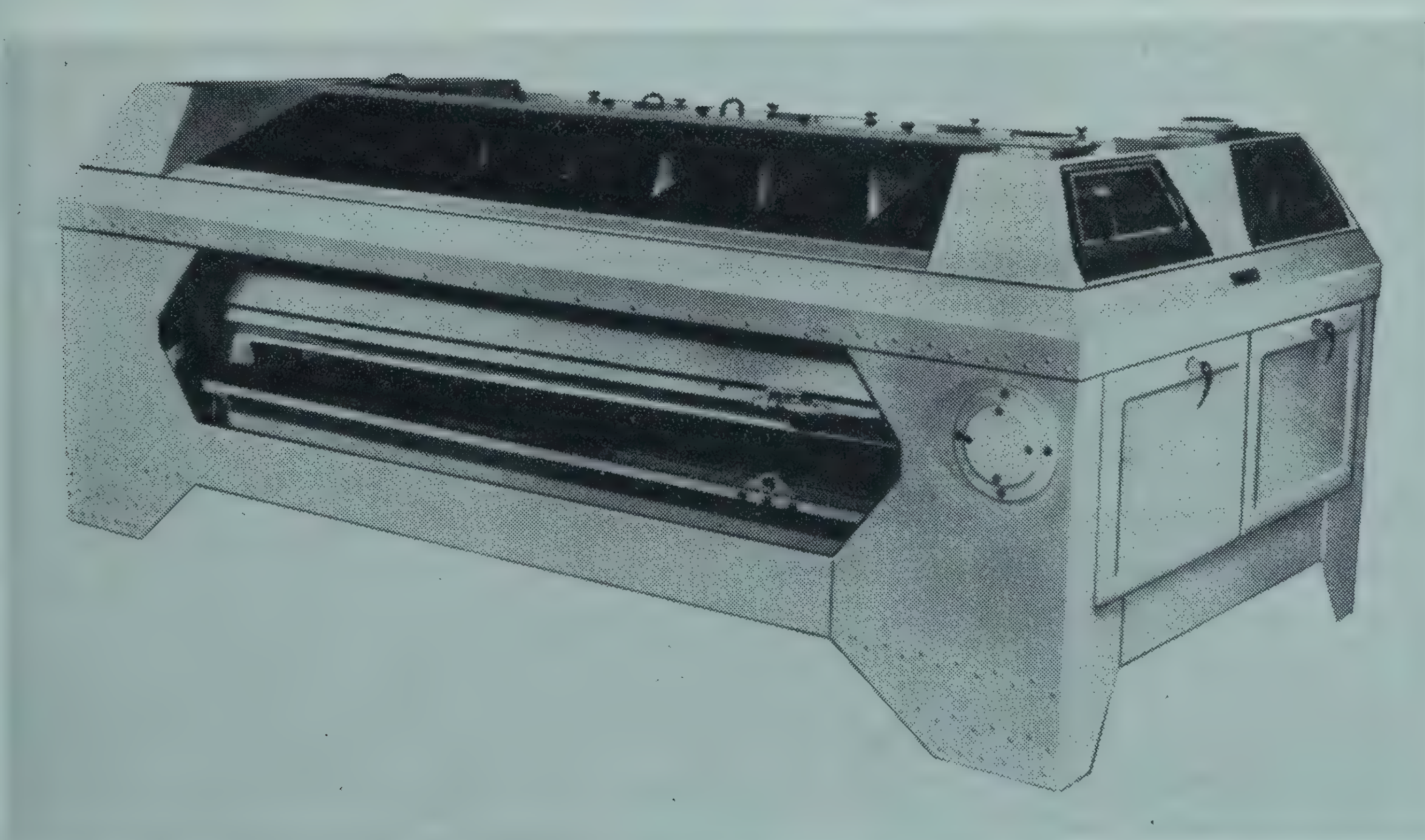
The reduction system comprises the smooth roller mills and the sifting machines. They reduce the endosperm middlings to flour size and facilitate the removal of the last pieces of bran and germ.

The roll stands in a reduction system are divided into coarse rolls and fine rolls. Coarse and fine does not refer to the condition of the roll surface since the surfaces are smooth. Rather, it refers to the setting of the rolls, whether they are set wide to produce coarse grinding or close to produce fine grinding. The coarse rolls are used only to produce middlings of uniform size for later reduction to flour. Hence, these rolls are often called sizing rolls and the middlings sent to them are called "chunks." Middlings sized on the sizing rolls are then sent to the fine rolls to be ground to flour.



Courtesy Thomas Robinson and Sons, Ltd.

FIG. 54. A PLANSIFTER FOR FLOUR



Courtesy Simon-Carter Co.

FIG. 55. A PURIFIER FOR FLOUR

After each reduction, the resulting product is sent to sifters where a classification by particle size is done. Finished flour is removed and oversized material is sent back to the reduction rolls for further processing.

One must be careful in the reduction system not to overgrind the flour. Overgrinding damages starch granules and makes the flour unsuitable for baking. Overgrinding can be detected by the high maltose value (see wheat flour specifications).

Overgrinding should not be confused with grinding too fine. It is possible to grind flour very fine without starch damage if the grinding is done gradually. However, great grinding pressures will cause starch rupture and this is to be avoided (Jones 1940).

The Reduction Sifting Systems

Most of the sifting system following the reduction rolls involves plansifters. This is true because the effect desired is one of size separation rather than bran or germ removal. The stock is divided into coarse middlings, fine middlings and flour. The coarse middlings are returned to the coarse (or sizing) rolls, the fine middlings to the fine rolls and the flour is removed from the system. Plansifters do this job very efficiently.

It is true that purifiers are often used behind the coarse reduction rolls. The purpose in this case is also size grading rather than purification. The range of flexibility for the size classification of middlings is greater for a purifier than a plansifter, and this accounts for the preference for this machine here.

Normally, for every reduction roll stand, there is at least one sifting device to take care of its output.

The Scratch System

In addition to the break system and the reduction system, most mills have a standby system called the scratch system. This system is normally apart from the main stream of the mill.

If the mill is operating properly, that is the tempering is such that good release of endosperm is obtained on the break, the scratch system can be by-passed. If not, the scratch system is employed to maintain proper release of endosperm from bran. Therefore, the scratch system is in reality an extension of the break system.

The Conveying System

Some means must be provided for the transport of flour stock from machine to machine. Most mills depend upon gravity, and this is why flour mills are so high. The wheat flour is moved up by bucket elevators (that is, endless belts having attached buckets which pick up the flour

at the bottom and dump it at the top), and then the flour flows by spouts to the rolls and to sifters. Several elevations are needed for the complete milling system, and one is impressed by the maze of pipes and spouts that are seen on the operating floor of a flour mill.

Bucket elevators have two serious disadvantages. They are dusty and they provide a place for insects to grow. Consequently, most modern mills, while they still depend upon gravity for downward flow, have gone to air conveying of flour in place of bucket elevators.

Under appropriate air velocities, solid matter such as flour is lifted from its solid mass bed and will flow like a liquid. The air force may be pressure or vacuum and in flour mills, vacuum is used. Powerful suction fans provide the negative pressure. The air intake is through the roller mills, and this air has the desirable effect of keeping rolls and flour stock cool during grinding.

Pneumatic conveying is the term applied to this system in flour mills. The higher power costs are offset by cheaper construction, less mill cleanup, less infestation, cooler stocks, and metal rather than wood spouting. In addition, some millers claim greater yields caused by the detachment of endosperm from bran during conveying.

THE STORAGE AND PACKAGING OF FLOUR

The bulk handling of flour is coming into importance. Not only is the flour conveyed by trucks and by railroad cars, but in addition to wheat bins, large flour bins are now also an integral part of the flour mill. All this has been made possible by pneumatic conveying systems.

Bulk storage flour has a number of advantages. Paramount is the ability to blend flour after milling to achieve optimum quality. Another advantage is that adequate storage of flours allows greater milling flexibility. Different grades can be milled out and held until needed. This increases running time on a mix and avoids costly machine setting changes that are required as one changes over from one wheat mix to another.

Practice varies widely but most newer mills that have bulk flour storage can hold from 2 to 4 days of production.

The movement of flour in bulk is particularly important in the United States. Special railroad cars called air slide cars are provided for this purpose.

Early concern for the quality of flour transported by railroad cars or trucks has proved unfounded (Pratt 1958). This sort of transportation is increasing.

Most flour, however, is still packed in bags weighing from 2 to 100 lbs. The larger bags are for bakery use, the smaller for the consumer market.

Large bags are packed by automatic packers which require only that

the 100- or 50-lb. bag be manually fitted on a spout. The bag is automatically filled to correct weight and stitched. In some cases, the bag is filled through a spout which is an integral part of the container and the spout is then tucked into the bag completing the seal. This eliminates the need for stitching. About ten bags a minute can be filled this way.

Smaller bags are filled on automatic machines which place the bag, fill, weigh and seal automatically. The fastest machine on the market today operates at about 50 bags a minute.

The handling of sacks in the warehouse involves the use of automatic conveyors, palletizing and lift trucks. Since such operations are not unique to the dry milling industry, they will not be discussed further here.

Courtesy The Simco Co.

FIG. 56. A HIGH SPEED FLOUR PACKER FOR SMALL PACKAGES

THE MILLING OF CORN

In contrast to the milling of rye, durum and flour, there are many mills, particularly in southern United States, where corn milling is still done on mill stones. Such stone-ground corn meal is made from the total corn seed and is an unbolted whole corn product. These mills are small and they are local in distribution. Rancidity and infestation are problems which limit the distribution of stone-ground whole corn meal.

There is a rather logical explanation for the continued existence of these small milling units in the corn milling industry. Not until 1906 was there developed a suitable method for the removal of corn germ from the corn berry. Roller mills are not too successful because of their tendency to break the corn germ into very small pieces. Thus, a new system of degermination was needed. In 1906, the Beall corn degerminator which answered this need was introduced to the dry corn milling industry.

The Beall corn degerminator is still used in most of the dry corn mills which produce degerminated corn meal or corn flour products. This device is a cone-shaped shell rotating around a stationary inner cone. Corn is fed in the smaller end of the cone and works its way down to the large end. During the passage, the corn is rubbed between the stationary cone and the rotating cone, both cones having special knob-like and auger-like surfaces. During the rubbing, the corn is dehulled and the germ loosened and knocked out. In other words, the Beall degerminator is an attrition device.

Entoleters can also be used for dehulling and degerming. The Entoleter differs from the Beall in that it is an impact rather than an attrition machine. Corn is fed through a center opening in the Entoleter and falls on a rapidly rotating disk containing pins on the surface. The pins of the rotor throw the corn against a stationary wall thereby dehulling and degerming it.

In either case, that is after the Beall or the Entoleter, the mixture of corn endosperm, germ and bran resulting is sent through rolls to flatten the germ so that it, along with the bran, can be removed from the endosperm by sifting.

Beside the problem of degerming, another problem in corn milling is the extreme irregularity in the size and shape of the corn kernels from the same ear of corn. This irregularity is even greater among different types of corn. Moreover, elevators commonly mix varieties before they reach the miller so that the different problems of corn particle size become compounded.

As with other types of dry cereal milling, the object of dry corn milling is to make the cleanest separation possible of endosperm, bran and germ. During this operation, one wishes to recover the greatest amount of endosperm.

Tip caps are found at the end of the corn germ and are a problem peculiar to corn. Since they are an intense black color, their presence in the corn flour in small amounts badly discolors the flour. Tip caps are to be avoided in dry corn milling and are removed with the corn bran by aspiration.

With these exceptions which have been mentioned, dry corn milling is in general like wheat flour milling. Upon receipt, the corn first goes through a cleaning process. Both dry cleaning and wet cleaning processes are used. The use of an electrostatic separator deserves special treatment.

This instrument finds particular use in the dry corn milling industry for the removal of rat pellets. Because of the relationship of the size and weight of corn kernels to the size and weight of rat pellets, separation by

sifting is difficult. Electrostatic separation fortunately works very well. Usually the electrostatic separator is added at the tail end of reels and disk separators and just before the wet stoner and washer.

After cleaning comes conditioning. Normally, the moisture content of the corn is raised not to 17 per cent as with wheat but to about 21 per cent. This is done because the germ of corn tends to be more friable than the germ of wheat and if it is too dry it will break into small flour sized pieces during degerming. If enough water is added, not only the bran is toughened but so is the germ. Conveyors and whizzers both add moisture to the corn.

Degerming follows the conditioning according to procedures already discussed. Following the degerming (and dehulling), the corn must be dried so it can be handled on roller mills and in sieves. The moisture is brought down to about 15 per cent. Inclined barrel shaped rotary driers are used and the product is air cooled after drying in louvered coolers. At this point, the product is aspirated to remove the bran and then is ready for the main part of the milling system.

The milling system consists of grinding, sifting and classifying, purifying, aspirating and possible final drying. The normal flow is through break rolls and then to plansifters. The fines go to the next break roll and the coarse goes to purifiers and then to the germ rolls. The germ rolls flatten the germ so that it is easily removed by sifting. The break rolls are followed by reduction rolls which produce the final fine flour.

The break system is longer in a dry corn mill than the reduction roll system. This is quite understandable since corn flour is not as important a product as corn grits or corn meal. Hence, a long reduction system is not needed to reduce the size of the endosperm particles (see corn products specifications).

Careful treatment of the germ in the dry corn milling industry is accomplished by special system of rolls which is set aside for the cleaning of the corn germ. In wheat, the germ makes up about 2.5 per cent of the wheat berry. In corn, the germ comprises twelve per cent of the berry. Moreover, the fat content of wheat germ is about eight per cent while the fat content of corn germ is higher—nearly 34.5 per cent. Thus, it is economical and also desirable to extract the oil from corn germ and sell it as corn oil. This requires clean germ and hence the emphasis of the corn germ milling system in contrast to wheat milling.

Every dry corn milling plant has an oil extraction plant. Normally, they use an oil press to extract the oil. The extraction and refining of corn oil is discussed in a subsequent chapter and will not be considered further here. Several excellent references are available (Stimmel 1941, Stiver 1955, Neenan 1951, and Gehle 1937).

THE MILLING OF RYE

There is much more similarity between the milling of rye and the milling of wheat than there are differences (Blank 1958, Prochazka 1938, Nottin 1945, Mayer 1936, and Zwilingenieur 1956). In either case, the object is to produce a powdery or granular material from a cereal grain by careful pulverizing of the seed. In both instances, the purpose is to make the flour substantially free of bran and of germ. The same basic type of machinery is employed. The novice might have trouble distinguishing a rye mill from a wheat flour mill although the differences would be immediately recognizable to one skilled in the trade.

For example, one finds roller mills that are apparently identical to the roller mills found in a wheat flour mill. Both break roller mills and reduction roller mills are employed in rye as in wheat flour milling. One might expect, however, to find differences in the corrugations on the rolls, and these do in fact exist.

Following grinding, the screening systems employ plansifters just as are found in a wheat flour mill. One is immediately struck by the fact, however, that there is little evidence of purifiers as are commonly used in wheat flour mills. This is the first major difference between rye and wheat flour milling.

The lack of purifiers is important since it immediately indicates that there is not a premium on the production of middlings on the break rolls of a rye mill.

This brings up a second and very basic difference between wheat flour milling and rye flour milling. In wheat flour milling, the point is to make as much middlings and as little flour as possible on the break rolls. In rye milling, one tries to make as much rye flour and as little middlings as is possible on the break rolls. Essentially, this is done by applying more pressure on the rolls although the type of surface on the break rolls—that is the corrugations—also plays a part. As a consequence, there are more break rolls in proportion to reduction rolls in a rye mill than in a wheat flour mill. This follows since there are less middlings that must be reduced to flour particle size on reduction rolls.

Returning to the first part of the rye milling operation, one finds here also great similarity in the cleaning house systems when comparing rye and wheat milling. However, because the cleaning process for rye is more difficult than for wheat, this cleaning operation must be more carefully controlled. The special problem with rye is occasioned by the fact that rye grain, in contrast to wheat, varies more in size. It is because of this that rye is graded for size as well as dockage and moisture. For example, a No. 1 plump has no more than 5 per cent thins while No. 3 rye has over 25 per cent thin grains.

Because of the size differences, in the cleaning house of a rye mill there are found gravity tables which separate according to weight differences. The use of these tables in a wheat cleaning house is not necessary and, therefore, not found.

Ash and protein are not important specifications in the sale of rye flours. Color is a much more critical specification. The granulation of the rye flour (this is generally called "dress") is a second important criterion. Flavor is a third.

This lack of importance of ash and protein is readily understandable. Rye protein in contrast to wheat protein will not readily form a gluten. Thus, rye bread is normally a blend of wheat flour and rye flour. As a consequence, the baker is more interested in appearance and taste qualities of the rye than he is in the baking quality.

THE MILLING OF DURUM

The method of milling durum is similar to the milling of wheat but the purpose is quite different. In the milling of wheat, flour is the desired end product. In the milling of durum, middlings are wanted. Consequently, in a durum milling system, the break system—where middlings are formed—is emphasized, and the part of the reduction system where flour is formed is deemphasized (Paige 1936 and Ager 1912). Reduction for middling sizing rather than flour production is the desired action.

Durum goes through the normal cleaning house and tempering operations used for wheat. Since the natural yellow color of durum is wanted in the final middlings (called semolina when applied to durum milling), the job of the durum wheat buyer is important. It is he who is responsible for maintaining constant color of desirable quality in the durum mix.

The tempering of durum while using the same equipment as wheat is different in that the times used are relatively less than for wheat. This is because of the desire for middlings without flour production. Excessive times in temper soften the endosperm making it easier to make flour. Short times maintain the hard structure of endosperm which encourages the production of endosperm chunks. Consequently, short time tempering is used.

The break system in a flour mill normally numbers four. In a durum mill at least five breaks are used. Such a system provides very gradual reduction of the stock so necessary for good middlings production while still avoiding large amounts of break flour.

The rolls in a reduction system are used as sizing rolls only. None is used to produce flour. They function the same as the sizing rolls in a flour mill reducing the coarse middling to a uniform particle size. In a flour mill, the sizing is done to produce a uniform product for further

grinding on the reduction rolls. In a durum mill, however, sizing is done to make a uniform product for sale.

Normally, the sizing rolls in a durum mill are corrugated on their surface. If a mill has five breaks, it may have five sizing rolls. Two rolls handle the large chunks, the rest smaller endosperm particles.

Some durum mills have several rolls set aside for the production of durum flour. However, since this is not the primary product of durum milling, these rolls are usually apart from the main milling system. Durum flour is particularly desired for noodles.

The sifting system of a durum mill differs from a flour mill by the heavy reliance on purifiers. Actually, plansifters are little used. Rather, conventional sieves are much more in evidence. These are used to make rough separations ahead of the purifiers.

The reason behind the predominance of purifiers in a durum mill has been discussed in the wheat flour milling part of this chapter. Not only are purifiers excellent for the removal of bran from middlings, but also they are much more efficient than plansifters for the size separation of middlings. Since middlings are the prime product of durum milling, the heart of a durum milling system is the purifiers found in that mill.

GENERAL TESTS FOR CEREAL FLOURS

Introduction

Each class of cereal flours has its own peculiar yet important specifications. Yet, on the other hand, there are certain specifications that are common to all. These more general tests are moisture, protein, ash, color, fiber and particle size.

Moisture

Air ovens are commonly used to determine moisture in flour. Holding the sample at 266°F. for one hour using constant air movement are the usual conditions.

In recent years, a number of semi-automatic ovens have been developed using a variety of heat sources. The Carter Simons moisture tester and the Brabender moisture tester are two of this type.

Protein

There is only one method of importance for measuring the protein content of cereal products. This is the time-tested Kjeldahl technique. In this method, the product is digested by the application of heat and strong sulfuric acid. The nitrogen is converted to ammonia which forms a salt with the sulfuric acid. After the solution has cooled, the ammonia is

released by adding a strong base, the freed ammonia distilled into a standard acid solution and the excess acid determined by back titration.

In this way, the amount of nitrogen in a cereal is determined. By using a factor, the per cent nitrogen is translated into per cent protein.

Ash

The importance of ash determination will be discussed in the flour specifications part of this chapter. The higher the ash, the more impure the flour. Therefore, ash is used as an indication of flour grade.

The principle of this test is to burn the cereal flour until all organic material is converted to gases. These are driven off along with water. The residual materials are metallic oxides. After cooling, these are weighed and the per cent of ash is determined.

Normally, this determination is made in a muffle oven at temperatures between 425° and 600° F. The holding time varies from a minimum of two hours to overnight.

Color

There are two ways to measure the color of cereal flour. One is a visual examination and the other is the use of an electronic machine which does the job automatically.

One visual method is called the Pekar Color Test. Samples of the flour are placed side by side on a flat glass or metal plate. The surface of the flour is smoothed using a spatula. The slicks are then immersed in water and air or oven dried (wheat, rye, or corn flour) or examined unwetted (durum).

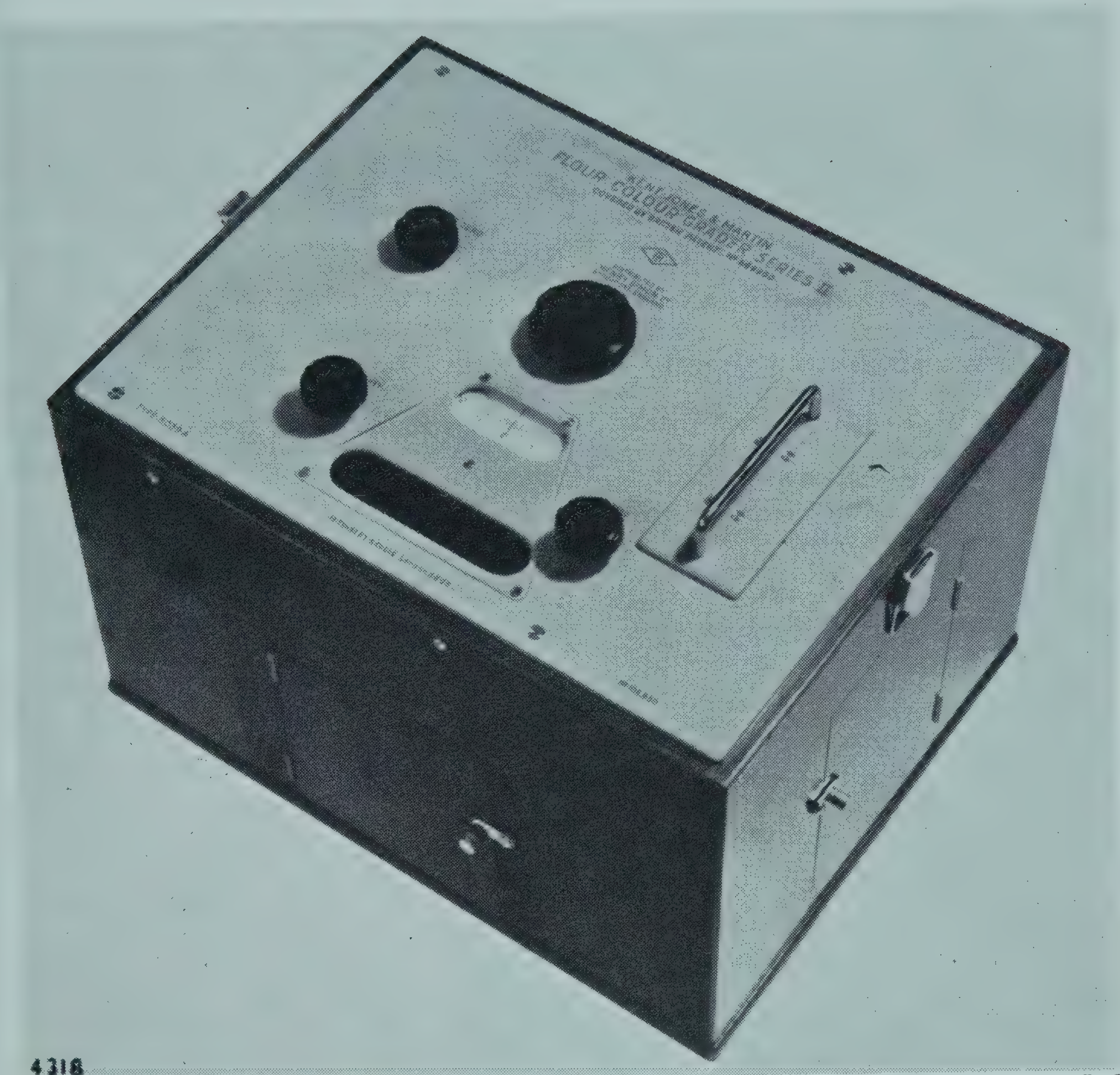
The wet Pekar process intensifies the dark color of the off-grade flours. Bran specks are easily seen. The flours are graded visually in comparison to a standard product.

The Kent-Jones and Martin Color Grader is an automatic instrument widely used today.

The flour is made into a water-flour paste. Light of a yellow wave length is allowed to impinge on this paste and the degree of reflectance is measured (Kent-Jones *et al.* 1950). The whiter the flour, the higher the reflectance value.

Determination of Fiber

To determine fiber, it is necessary to extract with ether and then digest the sample first with dilute sulfuric acid and then with dilute sodium hydroxide. After each digestion, the solubilized carbohydrates and proteins are removed by filtration and washing.



Courtesy Henry Simon Ltd.

FIG. 57. KENT-JONES AND MARTIN FLOUR COLOR GRADER

The residue is fiber and minerals. It is placed in a tared crucible and incinerated. The loss in weight is equal to the crude fiber.

Particle Size

There are four general methods of measuring particle size. These are sieve analysis, microscopic measurements, sedimentation techniques and air permeation techniques.

Sieve analysis depends upon the passage of cereal products through standard mesh sizes of graduated size and under standard conditions. The per cent of material on each sieve is determined. A machine called a Ro-tap is widely used, which through mechanized agitation assures standardized test conditions for the sieving. This type of analysis is used for cereal grains and for some cereal products.

For smaller particles, microscopes are often used. A calibrated eye-

piece is used when measuring particle size this way. A representative sample is brought into the microscopic field and the number of particles in each linear range counted.

Sedimentation techniques depend upon Stokes Law which says that in a liquid or a gas, larger particles of equal density settle more rapidly. Therefore, the amount of a sample which precipitates in a given time is measured and by application of Stokes Law, the dimensions of the particle calculated. From these data, a size distribution curve can be drawn.

Many devices are available using this principle. The Gallenkamp Particle Size Analyzer is one. Others are the Palo Travis Particle Size Analyzer and the Mines Safety Appliances Particle Size Analyzer (Loska 1958).

Air permeation techniques can be used to measure the particle size of cereal products. As the size of the particles becomes smaller, the apparent density of a collection of them becomes greater. Thus a given volume of small particles will give more resistance to the passage of a liquid or a gas than will the same volume of large particles. The time required for passage of a given volume of gas at constant pressure, or the pressure required to pass a given volume of gas in a given time, is measured.

A satisfactory instrument based upon the principle of air permeation is produced by the Fisher Scientific Company. This device is called the Sub-Sieve Sizer (Fig. 58).

Fat

The fat content of cereal products is estimated by solvent extraction procedures. A sample of well dried material is extracted with anhydrous ether for from 4 to 16 hours. Next, the ether is driven from the fat by heat and the ether-free fat sample weighed. The percentage of fat in the original material is calculated.

SPECIAL TESTS FOR WHEAT PRODUCTS

Introduction

In addition to the general tests just discussed, there are several more specific tests that are applied primarily to the products of wheat milling. These are protein quality, starch quality, hydrogen ion concentration and baking tests.

Gluten Quality

Besides the amount of protein (Kjeldahl test), flour millers must take into account the quality of the protein. This quality is referred to as strength and is related to the fact that strong glutens in a dough (gluten

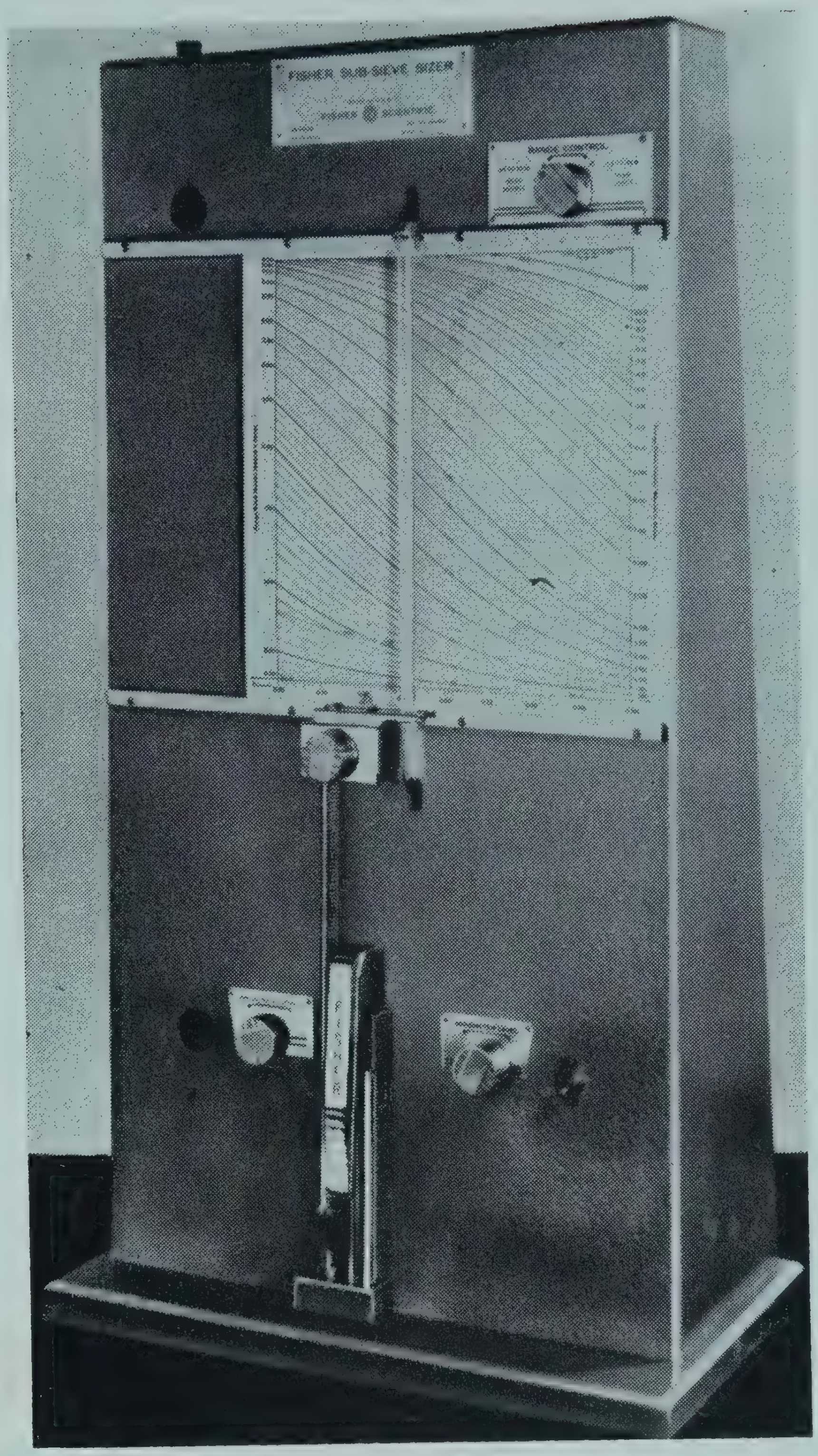


FIG. 58. SUB-SIEVE SIZER FOR PARTICLE SIZE ANALYSIS

Courtesy Fisher Scientific Co.

refers to the complex of proteins in flour) resist extension and that the gluten dough strands break before the extension is very great. Such gluten is wanted for bread. Weak glutens are easily extended and can stretch long distances (i.e., are plasto-elastic). These glutens are better for cookies, pastries and cakes. Biscuit flours are intermediate.

In Europe, the determination of gluten quantity and gluten quality is done at the same time. This is by washing the gluten from the flour using an automatic device (Theby Test) and weighing the resulting gluten dough ball. Since water is present, the weight of the dough ball is greater than for the calculated Kjeldahl protein. The dough ball gluten results when divided by three roughly approximate Kjeldahl protein values.

The gluten is suspended in a lactic acid solution and shaken. The weaker the gluten, the more goes into colloidal solution and the greater the solution cloudiness. Turbidity measurements are made on this lactic

acid-gluten suspension. The values obtained are related to gluten strength (Biechy 1957).

Gluten strength is measured on other types of special machines. The resistance to mixing is one factor that can be measured. The Mixograph and the Farinograph (Fig. 59) are two machines using this idea. In these devices, the flour is mixed into a dough under standard conditions and the resistance to this mixing procedure with time is measured. The resulting curve is a measure of flour strength. The length of time in

Courtesy C. W. Brabender Instruments Co.

FIG. 59. THE FARINOGRAPH, AN INSTRUMENT USED TO MEASURE THE MIXING PROPERTIES OF A FLOUR

minutes that it takes for the curve to descend from the peak height to below the 500 line is called the C Dimension. The greater the C Dimension, the stronger the flour protein.

For the measurement of gluten strength, the extensometers (Fig. 60) appear to be most sensitive. For example, the effect of dough strengthening agents (oxidizing compounds such as bromates and iodates) and dough weakening agents (reducing agents such as sulfites and sulfhydryls or proteolytic enzymes) are easily detected (Sullivan 1948).

A third method of measuring gluten strength, the MacMichael Test, is related to the Theby Method. Flour is suspended in a weak lactic acid

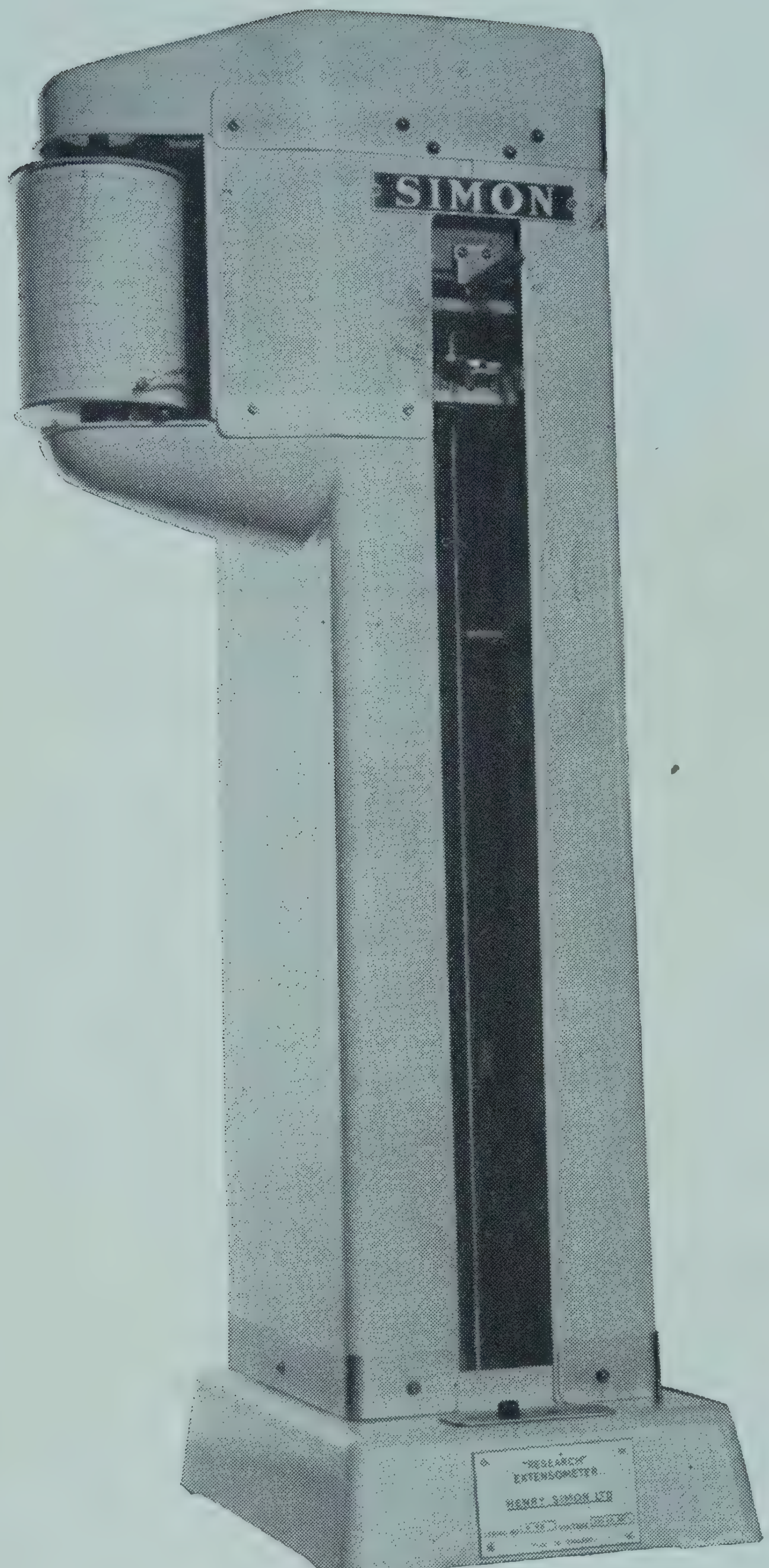


FIG. 60. THE EXTENSOMETER—AN INSTRUMENT USED TO MEASURE THE STRETCHING PROPERTIES OF A DOUGH

Courtesy Henry Simon Ltd.

solution and the gluten allowed to swell. Then, the resistance of the swelled gluten to the shear in a spinning bowl is measured on a MacMichael viscometer. The results are reported in degrees MacMichael. The greater the resistance, the greater the strength of the gluten.

Starch Quality

Starch makes up in excess of 80 per cent of the flour. The quality of this starch, particularly the degree of structural damage that has occurred in milling, is of particular importance. If there is not enough damage, enzymes cannot convert the starch to sugars so necessary for the metabo-

lism of yeast during fermentation. Thus, in bread flours, a degree of starch damage is desirable. If too much starch damage occurs, the baking quality of the flour, particularly in cakes, cookies and biscuits, is harmed. Consequently, tests of starch damage are particularly important.

One such test determines the amount of maltose freed from starch during the milling process. In this test, the amount of reducing sugars is measured. The flour is buffered and held at 86° F. for one hour. The amount of reducing sugar is determined with thiosulfate and the results expressed as mg. of maltose in ten gm. of flour. Results may vary from 100 to beyond 500.

Another method of measuring starch damage is to allow yeast to ferment the flour under standard conditions and to measure the amount of gas produced. The amount of maltose is the limiting factor. This test is called gassing power.

Finally, the Amylograph, an automatic physical testing unit, is now in wide use. This device heats a starch-water paste under controlled conditions which involve a set time and about a one degree F. rise in temperature each minute. During this time, the viscosity of the paste is being measured and automatically recorded. At some certain point, the crystallinity of the starch will begin to be disrupted and the molecules begin to swell. This swelling increases the viscosity and is so recorded. If the starch is mechanically or enzymatically broken, gelatinization will begin at an earlier temperature and the peak viscosity will not be as great.

Hydrogen Ion Concentration

Some soft wheat flours, particularly cake flours, are treated with gaseous chlorine to weaken the gluten. In this reaction, hydrochloric acid is formed. Therefore, the pH of a flour suspension can be used as a measure of chlorine treatment.

Baking Tests

The tests just described are an attempt to predict by chemical and physical techniques the baking quality of a flour. In the last analysis, however, a baking test must be applied.

It is virtually impossible to standardize on a baking procedure. The types of products made in different lands or in different shops within a country vary greatly. Each producer has his own peculiar set of conditions.

Therefore, each baker has devised his own particular test which suits his own conditions and the miller in that local baker's area must adjust accordingly. There can be no uniformity in these tests.

If the reader wishes some reference as a starting point for a baking procedure, the standard baking tests in the Cereal Laboratory Methods (Anon. 1957) are recommended.

SPECIFICATIONS FOR WHEAT PRODUCTS

Introduction

There are two general classes of products coming from a wheat mill. These are the flour and the millfeed. While percentages vary somewhat, they hover around 70 per cent flour and 30 per cent millfeed. In turn, these two general classes are subdivided into products depending upon the degree of purity desired. A list of these subclasses follows.

- 70 per cent Straight Flour
  - Patent flour (less than 70 per cent of wheat)
  - Clear flour (residue left when a patent flour is removed from a straight flour)
- 30 per cent Millfeed
  - 14 per cent bran (seed coat material left after milling flour)
  - 2 per cent germ (wheat seed embryo)
  - 14 per cent shorts (everything left after the bran and germ have been removed from millfeed)

These terms apply only to milling in the United States. Other terms are found in other countries. Lockwood (1952) has an excellent comparison of terms for similar products as they exist in different lands and so does the Miag milling dictionary (Kessler 1954).

The terminology for flour is confusing to the milling novice. Names such as short patent and first patent or first clear and second clear are commonly used. One needs only to remember that all of the flour coming from a mill is called straight flour. If it is further purified, it is separated into two fractions—a patent flour and a clear flour. The better of the two flours is the patent flour. The other flour after the removal of a patent from a straight flour is a clear flour.

This terminology applies to all types of flours whether they be cake, pastry, cookie, biscuit or bread flours.

The best measure of the degree of refinement of a flour is either ash content or color. These are measurements based upon sound considerations. The most refined flour comes from the center of the wheat berry and the least refined next to the bran. As one approaches the bran coat during milling, bran specks begin to appear, causing a discoloration of the white flour—hence, the validity of flour color measurement as an indication of quality (Kent-Jones *et al.* 1950). Also as one approaches the bran coat, the innermost bran layer, the aleurone layer is scraped away. Since the aleurone layer contains about 60 per cent of the ash of

wheat (Shetlar *et al.* 1947), the ash of the resulting flour rises very sharply. Thus, low grade flours coming from near the bran are high in ash and ash becomes a measure of flour quality.

Although it might be natural to assume that flours of the same degree of milling purity would have the same uses for baking, this is not necessarily true. Some wheat flours are better for bread and some are better for cakes. Intermediate stages lie between these two extremes. Most importantly, these flours differ in protein content (Atkins and Geddes 1939, Finney and Barmore 1948). In bread, one wants lots of tough elastic gluten since gluten is the structural component of the bread loaf. In cakes, this type of gluten is not wanted. Less gluten and gluten having a soft characteristic is the objective here.

Particle size is becoming of more importance in wheat flours (Shellenberger *et al.* 1950). While the effect of particle size is not clearly understood, it is probably related to the starch gelatinization conditions found in the particular product in which the flour is to be used.

Bread Flour

Miller and Johnson list some 27 different tests for determining the quality of a flour for bread baking (Miller and Johnson 1954). Many of these tests measure the same properties. Individual choices depend upon convenience, availability of equipment and particular relationship to shop conditions. No one test can be considered best under all conditions.

In this section, only certain of these many tests will be described. The reader must recognize that other tests are available and commonly used to measure many of these same properties.

Here, bread flour is specified in terms of six constants. These are moisture, protein, ash, starch quality, protein quality and particle size.

TABLE 35

SPECIFICATIONS FOR BREAD FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Protein	Kjeldahl	11.5 Minimum	Per cent
Ash	...	0.50 Maximum	Per cent
Starch quality	Maltose	450 Maximum	Mg. Maltose/10 Gm. Flour
Protein quality	Farinograph	7 C Dimension, Minimum	Brabender Units
Particle size	Fisher	20 Minimum	Fisher Units

These constants are based upon United States conditions where highly mechanized bakeries are commonly found. Workers in other nations would take issue particularly with the minimum protein level since the wheats available to them are sometimes of lower protein and they have

been able to compensate for this fact by gluten conditioning in milling or by formulating around this flour to produce an acceptable loaf of bread.

Moistures as high as 16 per cent are quite common in Europe, particularly Northern Europe. This is because the combination of quick usage and cool climate minimizes the possibility of mold growth. But, where storage conditions are a problem, and this includes most of the United States, it is clearly established that 14.5 per cent is the maximum moisture that can be tolerated (Anderson and Alcock 1954).

Cookie Flours

In Europe biscuit flour means cookie flour whereas in North America, biscuit flour refers to a flour for a chemically leavened bread. This specification referring to cookies, therefore, also refers to European biscuits. A rather weak gluten is essential for good cookie production. Strong glutens prevent good cookie spread and hamper the molding of cookies to a specific shape.

TABLE 36

SPECIFICATIONS FOR COOKIE FLOURS

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Protein	Kjeldahl	9.5 Maximum	Per cent
Ash	. . .	0.44 Maximum	Per cent
Starch quality	Maltose	200 Maximum	Mg. Maltose/10 Gm. Flour
Protein quality	MacMichael	50 Maximum	MacMichael Units
Particle size	Fisher	12–18	Fisher Units

Pastry Flours

Pastry flours (such as pie crust flours) are related more to cake flours than to cookie flour in the sense that the tendency is towards a lower protein. A weak gluten is wanted.

Cake Flours

Cake flours are characterized by fine particle size, low protein content and weak gluten. A special problem in producing cake flours is to get sufficiently fine flour without appreciable starch damage.

Cracker Flours

Soda crackers such as are made in the United States are made from low protein flours having relatively strong gluten. Actually, somewhat different flour types are used for the cracker sponge and the cracker dough.

The flour specifications given here are a compromise between the two types and are suitable for either cracker sponge or cracker dough.

Biscuit Flours

Biscuit flours are used for making the baking powder leavened biscuit common to the United States. These flours are higher protein products having relatively strong gluten characteristics.

Wheat Millfeed

The remaining products coming from a wheat flour mill are the bran, the shorts and the germ. A detailed description of the specifications for millfeed is available (Anon. 1958).

Table 41 gives general specifications for these products.

BLEACHING AND MATURING AGENTS

The author has left out of this discussion the use of chemical bleaching agents and chemical gluten-maturing agents. While such agents are allowed in the United States, in many other countries they are not and the miller must depend on wheat selection and physical methods of gluten conditioning.

For excellent discussions of bleaching and maturing agents, the reader is referred to the Kent-Jones book "Modern Cereal Chemistry" (1957) and an article by Harrell (1952).

SPECIAL TESTS FOR CORN PRODUCTS

Introduction

Moisture, particle size, fat content and visual appearance are important corn flour specifications. In addition, acidity and malt extract are special tests applied to this type of product.

Acidity

The acidity of corn flour products is important. This test, which is not generally applied to other cereal flours, is used as a measurement of undesirable microbiological action. If the acidity is high, the microbiological spoilage is high (Zeleny 1940).

The first step in the acidity test is to leach the free fatty acids from the flour. This may be done by shaking the corn meal with benzene or very commonly water to extract the acidic materials.

The liquid is decanted or filtered from the corn product and the fatty acid content of the filtrate determined by titrating with standard potassium hydroxide solution using phenolphthalein indicator. The results are calculated as per cent lactic acid.

TABLE 37

SPECIFICATIONS FOR PASTRY FLOURS

Type of Measurement	Test Used	Values	Units of Measurement
Moiture	Air oven	14.5 Maximum	Per cent
Protein	Kjeldahl	8.5 Maximum	Per cent
Ash	...	0.44 Maximum	Per cent
Starch quality	Maltose	200 Maximum	Mg. Maltose/10 Gm. Flour
Protein quality	MacMichael	40–50	MacMichael Units
Particle size	Fisher	12–20	Fisher Units

TABLE 38

SPECIFICATIONS FOR CAKE FLOURS

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Protein	Kjeldahl	8.5 Maximum	Per cent
Ash	...	0.36 Maximum	Per cent
Starch quality	Maltose	150 Maximum	Mg. Maltose/10 Gm. Flour
Protein quality	MacMichael	30–40	MacMichael Units
Particle size	Fisher	12.5 Maximum	Fisher Units

TABLE 39

SPECIFICATIONS FOR CRACKER FLOURS

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Protein	Kjeldahl	9.5 Maximum	Per cent
Ash	...	0.43 Maximum	Per cent
Starch quality	Maltose	200 Maximum	Mg. Maltose/10 Gm. Flour
Protein quality	MacMichael	65–85	MacMichael Units
Particle size	Fisher	15–20	Fisher Units

TABLE 40

SPECIFICATIONS FOR BISCUIT FLOURS

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Protein	Kjeldahl	8.0–10.5	Per cent
Ash	...	0.40 Maximum	Per cent
Starch quality	Maltose	250 Maximum	Mg. Maltose/10 Gm. Flour
Protein quality	MacMichael	40–70	MacMichael Units
Particle size	Fisher	12–18	Fisher Units

TABLE 41

SPECIFICATIONS FOR WHEAT MILLFEED

Product	Moisture	Protein	Fat	Fiber
	Per cent	Per cent	Per cent	Per cent
Bran	15.0 Maximum	14 Minimum	4.0 Minimum	12 Maximum
Shorts	15.0 Maximum	16 Minimum	3.5 Minimum	6 Maximum
Germ	15.0 Maximum	25 Minimum	8.0 Minimum	4 Maximum

Malt Extract

Since some corn flours are used in the brewing industry, it is necessary to get a measure of the degree of conversion of starch to soluble solids as an indication of the amount of fermentable carbohydrates. The determination in question is called the malt extract test.

In this test, the corn product is added to water and gelatinized. The gelatinized slurry is brought to around 140° F., ground malt is added, and the resultant product is stirred. The mixture is held at these conditions for a period of time to allow the malt enzyme to act on the carbohydrate. The temperature is then raised to boiling to inactivate the malt enzyme. The solution is cooled, filtered and the specific gravity of the filtrate measured. From tables on the relationship of specific gravity to sugar content, the amount of soluble solids is estimated and reported as per cent conversion.

SPECIFICATIONS FOR CORN PRODUCTS

Introduction

The corn kernel is somewhat unique in that the endosperm opposite the tip of the kernel is quite soft while the other parts of the corn seed endosperm are hard. When ground, the soft portion easily breaks into flour (called soft flour) while the rest of the corn endosperm stays as larger pieces. These larger pieces can be classified according to size or ground into flour. Such flour is called sharp flour.

The yield of endosperm products in corn milling varies between 65 and 70 per cent. The residual is bran, germ and shorts. These are combined to produce a product for animal feeding called hominy feed.

Before the germ is added to the hominy feed, however, the valuable corn oil in it is removed by expression and the use of filter presses (Stiver 1955). Thus, the germ in corn millfeed is a defatted product.

Classified by size, the products of corn milling are these:

Grits	6 to 16 USBS Sieve
Meals	
Coarse	16 to 24 USBS Sieve
Medium	24 to 40 USBS Sieve
Cones	40 to 70 USBS Sieve
Flours	
Sharp	70 to 100 USBS Sieve
Soft	70 maximum USBS Sieve

Soft Corn Flour

This flour comes mostly from the end opposite the tip of the kernel and lies between the flinty endosperm and the hull. It is separated from the meals and grits by sieving the early break products.

TABLE 42

SPECIFICATIONS FOR SOFT CORN FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Particle size	Screens	70 Maximum	USBS[1] Sieves
Fat content	Ether extract	2.0 Maximum	Per cent
Acidity	Fatty acids	1.0 Maximum	Per cent as Lactic acid
Appearance	Visual	Normal	...

[1] United States Bureau of Standards.

Sharp Corn Flour

This flour is produced by grinding to the proper size the flinty endosperm particles that come from the early break rolls and bolting the product to take out the flour-like material. The specifications are similar to those of the soft corn flours, but the feel of the product is harsh rather than soft. This is caused by the sharp edges of the flour particles in contrast to the rounded edges of the soft flour particles. Hence, the name sharp flour.

TABLE 43

SPECIFICATIONS FOR SHARP CORN FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Particle size	Screens	70 to 100	USBS[1] Sieves
Fat content	Ether extract	1.25 Maximum	Per cent
Acidity	Fatty acids	1.0 Maximum	Per cent as Lactic acid
Appearance	Visual	Normal	...

[1] United States Bureau of Standards.

Cones

This product is similar to the sharp flour except that it is coarser. It has the same feel to the touch as does the sharp flour.

Cones is often used by the brewing industries and is used where the dust from flours must be avoided in other food industries.

TABLE 44

SPECIFICATIONS FOR CONES

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Particle size	Screens	40–70	USBS[1] Sieves
Fat content	Ether extract	1.25 Maximum	Per cent
Acidity	Fatty acids	1.0 Maximum	Per cent as Lactic acid
Appearance	Visual	Normal	...

[1] United States Bureau of Standards.

Corn Meals

Corn meal is a product somewhat smaller than corn grits but still much coarser than a corn flour. Its chief use is for table consumption. In these cases, white corn products are used more often.

Corn meals are used to make gelatinized corn flour. Such flours find their way into industrial as well as food uses.

TABLE 45

SPECIFICATIONS FOR CORN MEAL

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Particle size	Screens	16 to 40	USBS[1] Sieves
Fat content	Ether extract	1.5 Maximum	Per cent
Appearance	Visual	Normal	...

[1] United States Bureau of Standards.

Corn Grits

Grits of screen sizes such as numbers 8, 10 and 12 are made. These products are used by breweries to make alcoholic products by fermentation. Each brewery has its own particle size desires. To change this would change the brewing conditions which are based upon definite cooking times and temperatures using predetermined formulas. Thus, close attention is paid to particle size.

Visual inspection is important in these grit products since, with such coarse materials, it is hard to remove adventitious substances by sifting techniques.

While formerly only white corn was used for the production of corn grits, the corn milling industry is turning to cheaper yellow corn. The brewers' antagonism to this type of grits largely disappeared during World War II.

Pearl Hominy

This product is sometimes called number four grits because it will pass through a number four screen but will remain on top of any finer screen. Its use is for the production of breakfast cereals. Normally, this product is made from white corn and not from yellow corn.

Visual inspection is of great importance. Freedom from foreign particles such as yellow corn, soybeans and insect refuse is a necessity before further processing to breakfast cereals is possible. Many of these foreign materials are of the proper size to concentrate with the number four grits during sizing. Thus, avoidance depends upon good milling practice and quality control by visual appearance.

TABLE 46

SPECIFICATIONS FOR CORN GRITS

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Particle size	Screens	4 to 16	USBS[1] Sieves
Fat content	Ether extract	1.0 Maximum	Per cent
Starch conversion	Extract	80 Minimum	Per cent
Appearance	Visual	Less than 1 per cent hull	...

[1] United States Bureau of Standards.

TABLE 47

SPECIFICATIONS FOR PEARL HOMINY

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Particle size	Screens	$3\frac{1}{2}$–4	USBS[1] Sieves
Fat content	Ether extract	0.75 Maximum	Per cent
Appearance	Visual	Less than 1 per cent hulls	...

[1] United States Bureau of Standards.

TABLE 48

SPECIFICATIONS FOR HOMINY FEED

	Moisture	Protein	Ash	Fiber	Fat
	Per cent	Per cent	Per cent	Per cent	Per cent
Hominy Feed	15.0 Max.	10.0 Min.	2.9 Max.	6.0 Max.	5.5 Min.

Hominy Feed

Corn millfeed is sold as one product, hominy feed. Hominy feed is a combination of corn bran, corn shorts and defatted corn germ. It is used in animal feeding.

SPECIFICATIONS FOR RYE PRODUCTS

Introduction

The overriding consideration in rye flour specifications is the fact that the protein content is not of great importance even though the product is used for baking. Rye protein does not form a gluten in the sense that wheat protein does. In fact, most rye bread contains some portion of wheat flour in order to produce a good looking loaf of bread. Usually, this addition of wheat flour exceeds 50 per cent.

Secondly, rye is the natural habitat for ergot. The fungus ergot is quite poisonous. Therefore, there is a limitation on the amount of ergot that can be tolerated in the rye grain. This limitation has been mentioned when discussing the specifications for rye seed.

The important factors in the milling of rye are dress, color and flavor. By dress, the rye miller is referring to the granulation of the product.

Rye is sold in all degrees of granulation. In Europe, whole rye is used as such in the production of pumpernickel bread. In this case, the bread is made by a long steaming process in order to gelatinize the rye kernel and thus to make it edible. In the United States, pumpernickel bread is made from a very coarsely ground rye meal. Much rye is sold as a cracked rye or a chopped rye on which there has been little milling except to break the rye kernel.

However, most rye is sold in two grades. One grade is rye meal and the other is rye flour. Rye milling yields 80 per cent of endosperm product (flour or meal) and about 20 per cent millfeed.

White, Medium and Dark Rye Flour

It is difficult to generalize on the information about rye specifications. The data in Table 40 hold for the United States but may not be typical for the world, particularly the European market.

TABLE 49

SPECIFICATIONS FOR WHITE RYE FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Ash	Muffle oven	0.58–0.78	Per cent
Color	Pekar	White	Comparison
Protein	Kjeldahl	7.0–9.1	Per cent

TABLE 50

SPECIFICATIONS FOR MEDIUM RYE FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Ash	Muffle oven	1.11–1.39	Per cent
Color	Pekar	Medium white	Comparison
Protein	Kjeldahl	10.1–12.8	Per cent

TABLE 51

SPECIFICATIONS FOR DARK RYE FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Moisture	Air oven	14.5 Maximum	Per cent
Ash	Muffle oven	2.05–2.83	Per cent
Color	Pekar	Dark	Comparison
Protein	Kjeldahl	13.7–16.2	Per cent

These figures indicate that there are three grades of rye flour—white, medium and dark. The white flour is the purest grade and comes from the first break rolls. As the rye proceeds through the milling system, the purity goes down as indicated by higher ash and deeper color. On the other hand, the typical rye flavor increases also. Therefore, these darker fractions should not necessarily be thought of as unwanted products. Actually, their flavor and dark color are to be desired.

Relating rye milling to wheat milling, the white rye flour is a patent grade, the medium rye flour is a straight grade and the dark rye flour is a clear grade. The high ash indicates that most of the rye bran is ground and finds its way into rye flour rather than rye millfeed.

Rye Meal

Rye meal is sold on a granulation specification. There are numerous varieties ranging from fine rye meal to the coarse meal sold for pumpernickel. Examples of the size distributions of the two extremes—the fine and the coarse—are shown in the next table.

Table 52

SIZE CLASSIFICATIONS FOR COARSE AND FINE RYE MEAL

USBS[1] Sieves	Pumpernickel Rye Meal	Fine Rye Meal
On 8	30	10
On 20	46	40
On 40	14	20
On 60	5	5
Thru 60	5	25

[1] United States Bureau of Standards.

Rye Millfeed

The offals of the rye milling are sold as middlings only. A bran product is not marketed.

Table 53

SPECIFICATIONS FOR RYE MILLFEED

Product	Moisture	Fat	Fiber	Ash
	Per cent	Per cent	Per cent	Per cent
Middlings	15.0 Max.	4.5 Max.	8.2 Max.	6.0 Max.

SPECIFICATIONS FOR DURUM PRODUCTS

Introduction

Durum milling, like rye milling, differs from wheat milling in a lack of concern about protein content of the products. Actually, the durum

crops are usually so limited that the durum miller has to take what nature offers. This is not to intimate that protein is not of some importance in the production of alimentary pastes. It is rather that protein is an uncontrollable factor. Not only quantity but protein quality is important. Normally, the protein content is somewhere above eleven per cent for the durum products. The ash content is high since the durum wheats are hard and are tempered lightly to give coarse granulations. The ash content of a durum flour which is the equivalent of a patent wheat flour would be above 0.60 per cent.

In durum milling, the millfeed products are similar to wheat milling. Bran, shorts and germ are made. The yields of endosperm products run between 70 and 75 per cent with the residual being millfeed products.

The durum endosperm products are divided according to size. The coarsest middling products are called semolina. The next smaller goods are sold as granular products and the finest material as durum flour.

Semolina

The important specifications for semolina are color, ash, granulation and per cent flour.

Flour is defined as anything finer than a 100-mesh screen. Three per cent flour is about the most that is tolerated.

Granular Product

There are many grades of granular product. The only restriction is that the product contain not more than 15 per cent durum flour. Granulations vary. The ash generally runs higher than semolina, being about 0.72 per cent maximum.

Durum Flour

Semolina and granular product go into macaroni and spaghetti goods. Durum flour, which is used for noodles, is generally defined as any material which will pass through a No. 100-mesh sieve. Actually, the product as it is made today contains much material which stays on top of a 100-mesh screen.

The range for ash is wide. This is in accordance with good commercial practice since durum flours may come from any place in the millstream. If the color and granulation properties are satisfactory, ash becomes of secondary importance. Methods for measuring color were described by Matz and Larsen (1954).

Durum Millfeed

In a botanical sense, durum is closely related to bread wheat. This might be inferred when they were classed together when considering

cereal grain specifications. This relationship is also indicated when considering millfeed products. There is a striking similarity in the specifications.

TABLE 54

SPECIFICATIONS FOR DURUM SEMOLINA

Type of Measurement	Test Used	Values	Unit of Measurement
Color	Pekar	Yellow[1]	Comparison
Ash	...	0.69 Maximum	Per cent
Granulation	USBS Sieves	On 30; 4	Per cent
		On 40; 20 to 40	Per cent
		On 50; 25 to 30	Per cent
		On 70; 20 to 30	Per cent
		On 100; 10 to 20	Per cent
		Through 100; 3 Maximum	Per cent

[1] Absence of bran specks is important.

TABLE 55

SPECIFICATIONS FOR DURUM FLOUR

Type of Measurement	Test Used	Values	Units of Measurement
Color	Pekar	Light yellow[1]	Comparison
Ash	...	0.60 to 0.72	Per cent
Granulation	USBS Sieve	On 100; 25 Maximum	Per cent
		Through 100; 75 Minimum	Per cent

[1] Absence of bran specks is important.

TABLE 56

SPECIFICATIONS FOR DURUM MILLFEED

Product	Moisture	Protein	Fat	Fiber
	Per cent	Per cent	Per cent	Per cent
Bran	15.0 Max.	14.0 Min.	4.0 Min.	12.0 Max.
Shorts	15.0 Max.	16.0 Min.	3.5 Min.	8.0 Max.
Germ	15.0 Max.	25.0 Min.	8.0 Min.	4.0 Max.

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L. A. Rumsey

Commercial Baking Procedures

INTRODUCTION

Bakers' breads and an ever increasing variety of baked foods must now compete for the consumers' choice with all the other convenience foods to be found on the grocer's shelves. These foods, in almost unlimited variety, have all been processed and packaged for extended keeping qualities and to preserve their natural flavors. Many of them are enriched with additional vitamins and minerals for greater nutritional values.

While the commercial production and sale of breads and other bakery products have developed side by side with the industrialization of many other foods, the baking process exhibits the peculiar anomaly of being at one and the same time an ages-old art and a modern science.

The Egyptians are credited with noting the accidental seeding of doughs with air-borne spores or yeast cells and the consequent leavening of those doughs into lighter, more edible breads. The propagation of that fermentation system and the improvement of methods for its control became the basis for the bread bakers' art down through the centuries.

After thousands of years of baking and its development into a universal art in home and market place, our knowledge of the fundamental principles of the process is a comparatively recent acquisition, and it is still far from complete.

Like so many of our new or modified food processes, the development of baking science had to await the discoveries of such pioneers in science as Lavoisier, Liebig, Leeuwenhoek, and Pasteur toward the end of the eighteenth century. Jago (1921) of England was one of the tireless experimenters who sought an application of the then known principles of yeast fermentation to breads in the early 1900's while Swanson (1941 and 1943) at Manhattan, Kansas, Osborne (1907), Carnegie Institute, Pittsburgh, and Bailey (1925 and 1944) at Minneapolis, among others, were directing the study and research of the complex interrelated problems of flour milling and the fermentation process in bread making.

BEGINNING OF SCIENTIFIC CONTROL

The baking industry generally knew little or nothing about scientific control principles for another 50 years after the pioneer work had begun.

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but believed that only long and arduous experience would suffice for a knowledge of dough fermentation. Consequently, in spite of the development of new bread making machinery for almost every step in the process, those in charge of production were handicapped by each seasonal fluctuation or milling variation in the flours they used.

With the advent of the machine age, all industries benefited by the application of new machine design, especially when steam power gave way to electric motive power that could be applied to individual machines. In the case of the baking process, practically every mechanical development designed to substitute the machine for hand work imposed modifications of the dough to some degree in order for the machine to handle it satisfactorily. Therefore the "almost" automatic baking factory of today has imposed many variations in the dough making process and consequently in the finished baked products. Because of, or in spite of, these changes in mechanical handling, the present products of the baking industry are now much better than the old in uniformity, tastefulness, and nutritional value.

Fortunately, consumer acceptance of the bakers' products during the early 1900's followed the convenience of more general distribution through the grocery stores. The added convenience of wrapped and sliced bread together with the practices of better sanitation, which followed by a few years the economic and social changes resulting from the first World War, speeded the growth of larger baking companies. Discovery of profit potentials by the bankers of the early 1920's led inevitably to financing of combinations of individual plants with the consequent formation of large corporations. These corporate entities, operating many plants in different markets and having the economic advantages of centralized control and purchasing power, were soon to feel the competition of another form of organized baking group, the chain store bakeries. One large plant could produce and distribute breads to many chain store outlets in the surrounding marketing areas through their own established warehouse and trucking system, with a large saving over the regular sales and delivery cost of the independent or corporation bakers. Besides having the price advantage, the chain store organization was able to control more closely the sales of their baked products.

A great fear of competition from both corporation bakeries and the chain stores caused the remaining independent bakers, who were limited to their own marketing areas, to seek such technical help as was available. This was found chiefly in the cooperative bakery service organizations and in the technical service personnel maintained by the larger allied distributors of machinery, flour, shortenings, yeast and other ingredients.

Men trained in cereal chemistry and in associated food sciences began to be sought to spread the word of technical baking knowledge and lead in the production of better products and in better production control.

The stimulus of World War I to scientific knowledge brought new candidates in the sciences by the thousands to our colleges and universities. Of these, the relatively few advanced students in cereal chemistry and baking technology were absorbed in the baking and allied industries where they continued the study of baking science and the development of new products and better methods. The American Institute of Baking was organized by the American Bakers Association in 1919 to serve the industry and help teach the fundamental principles of baking. The American Institute of Baking was an addition to the several trade schools then offering short courses of training in the baking field. Stimulation and more active support of research in cereal technology by the industry resulted in new knowledge for better control of the baking process and improvement of the products therefrom. Fundamental research was simultaneous in many other fields that contributed significantly to baked foods.

The phenomenal advances in biochemistry, physical chemistry, food technology and nutrition during the years since 1900 have revolutionized the baking industry through application to the economies and controls of production. Wheat culture studies in the agricultural experiment stations of many states paced the development of new strains of wheat better suited to special requirements of flours for a variety of cereal foods, from breads to macaroni. Mill chemists showed the way to blend and mill wheats from different growing areas and with somewhat diverse baking values into a flour that could be duplicated for more uniform baking use. Analytical and mechanical testing methods were worked out as an approach to specifications for and control of ingredients.

There were only a few scientists in the bread making field in the early 1920's but they had a profound influence on the development of baking technology. Also influential were the few individuals whose engineering skill and imagination led the industry toward more modern automation in bakery production. And it is here that science must take over from the so-called practical operator to maintain control of the physiochemical and biochemical processes that make up the mass production of baked products of uniformly high quality and nutritive values.

THE BREAD MAKING PROCESS

"Wheat is unique among all other cereals in that its milled product, flour, is alone capable of forming a dough that will retain the gas evolved during fermentation and upon baking yield a light well aerated bread"

(Pyler 1952). Wheat flour, being the selectively ground and sifted particles of the wheat seed, may be considered as a complex biological system of proteins, carbohydrates, fats and minerals in which the normal life process has been interrupted. The natural biological tendencies with which the seed was endowed, such as the enzyme reactions, continue to function to a degree modified by the moisture content, temperature, pH, time, and some of the other constituents of the bread formula. These other constituents are in turn further acted upon and modified by the fermentation system of the yeast in the dough. Since this heterogeneous mixture of actions and reactions does not lend itself to simple separation for the purposes of study and analysis, many parts of the process are as yet poorly understood. We therefore simplify the problem in order to explain the resultant product, namely, the dough when it is ready for baking into a desirable loaf of bread.

A word picture of the bread baking process as it has been developed in commercial practice in the United States should be sufficient to properly identify the fundamental principles involved.

Ingredients

The following can be regarded as a typical straight dough formula for white pan bread. Ingredient percentages are given in terms of flour weight at 100 per cent, which is the traditional method of expressing bread formula weights in the bakery.

	Flour Basis, Per cent
Flour	100.
Water	65. (variable)
Yeast	2.
Yeast food	0.25 to 0.50
Malt	0.5
Salt	2.
Sugar	6.
Skim milk solids	6.
Shortening	4.
Enrichment tablet	[1]

[1] Enrichment tablets are supplied with vitamin and mineral content suitable to bring the finished bread up to Federal requirements for enriched bread.

Other additives may be and are frequently used in commercial bread formulas. These may be in the form of additional enzyme materials containing oxidases, or amylases and small amount of proteases. Mono- and di-glycerides are commonly added as emulsifiers for finer grain and texture and longer shelf life (softness).

In actual practice, there has been a trend in modern bakery operation

Courtesy of Baker Perkins Co.

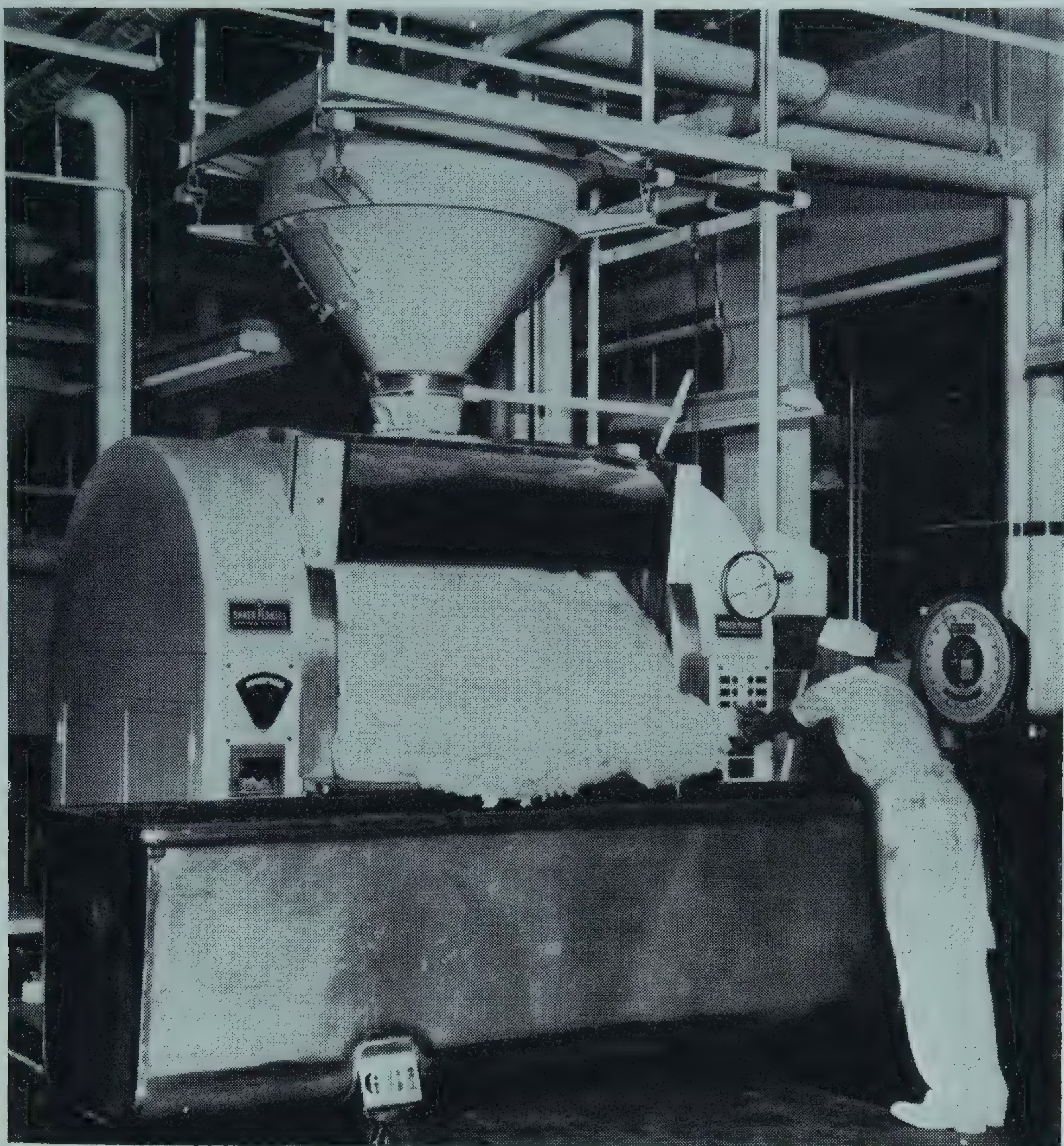
FIG. 61. BULK FLOUR FROM THE MILL IS FLOWED IN AND OUT OF STORAGE BY PNEUMATIC PRESSURE

The two steel bins in the pneumatic bulk flour system shown here have capacities of 20,000 lbs. and 40,000 lbs. of flour, respectively.

to add other ingredients for specific purposes and to increase the amounts of sugar and shortening in the bread doughs. The American public has shown a preference toward sweeter breads (those with considerable residual sugars) and the percentage added to the formula has slowly climbed for years until now many breads are made with eight per cent sugar.

Flour Supply and Storage

Wheat flours of suitable baking strength and milled to approximate specifications are shipped to the bakery from mills in various parts of the country. These flours, in one hundredweight bags, or in bulk, are stored in the bakery under normal conditions of circumambient temperatures and humidity. It was previously the bakers' practice to hold the new flour for four to six weeks of storage to allow it to go through the "sweat." That was a process of respiration and oxidation of the flour particles with the release of moisture during which time the doughs performed abnormally and the flour was considered unfit for normal fermentation and bread making. The application of bulk transportation and storage, however, have now made the flour usable immediately from the mill. The repeated aeration of the flour by means of forced air used to stream the



Courtesy of Baker Perkins Co.

FIG. 62. A MIXER FOR BREAD DOUGH

This stationary bowl mixer discharges 1600 lbs. of mixed dough into the dough trough for transfer to the make-up machinery.

flour from mill to air-slide bulk-flour car or truck, and repetition of that aerating action three or four times from car to bakery site or storage bin, again from the bins through sifters and into the mixer hoppers, apparently completes the biological activity of sweating. Thus the need for conventional six weeks of storage in the bakery has been eliminated by bulk handling. The application of tempered, conditioned air and adequate ventilation to flour storage areas has not been general in new plant design, but is gaining in practice.

Mixing Principles

Basically, mixing a bread dough consists of adding 65 to 70 per cent of water to each 100 lbs. of flour, and about 2 to 2.5 per cent of fresh

(compressed) yeast, with enough sugar to facilitate vigorous yeast fermentation. About two per cent of salt is used to help control gluten hydration and for flavor. Two to four per cent of shortening such as lard or other semisolid fat is added to improve the tenderness and texture of the dough and the finished bread. The shortening is considered as a lubricant only, but plays an important role during the early stages of baking in better control of cell wall porosity and structure, with resultant tenderness of crust and crumb. These percentage figures are all based on flour weight.

The mixing machine consists of a steel bowl with rotating arms which have the effect of thoroughly incorporating the ingredients while stretching, pulling, and rolling the dough to hydrate and develop the gluten of the flour to the point where it is soft and pliable and ready for the continuing action of the yeast fermentation. Bakery mixers are used in all sizes from a capacity of 200 or 400 lbs. up to 1600 lbs. of dough. High speed dough mixers with horizontal bowls operate at speeds of the mixing arms usually of 30 and 60 or 40 and 80 r.p.m.

For best results in mixing and subsequent fermentation, the dough temperatures are controlled usually between 78° and 80° F. Mixing bowl temperatures are controlled by circulating cold water or refrigerant through the jacket surrounding the bowl. Considerable power is required to thoroughly mix a dough against the resistance of the gluten, and temperatures build up rapidly in mixing unless controlled.

Straight Dough Mixing Process

The straight dough method, where all ingredients are incorporated and mixing completed in 8 to 15 minutes, depending upon the protein quality of the flour, is preferred in some bakeries where shorter fermentation time is desirable, and where critical fermentation conditions can be more accurately controlled and timed. The mixed straight dough is transferred (dumped) from the mixer into a steel dough trough of suitable size to contain the dough and moved into a fermentation room or cabinet while it ferments and is expanded to several times the original volume by the action of yeast fermentation.

The fermentation time, temperature, and expansion of the mixed dough are again critical. Usual practice is to allow the fermenting dough to expand to the point of the "first punch." This is the point at which gluten structure of the dough has been extended by gas pressure almost to the point of collapse. The fingers are carefully inserted a few inches into the surface and then withdrawn. If the dough surface at that point recedes slowly without filling up the depression, it is said to be ready for the first punch. The entire dough is knocked down or punched to remove

the gas, and turned over in the trough. This movement of the dough removes the excess concentration of carbon dioxide gas, tends to reduce the size of the gas cells, prevents large gas pockets, and makes the structure more uniform. It also puts the active yeast cells in touch with a fresh supply of food substances. Yeast action is thereby invigorated and proceeds at greater speed for a time. The punch procedure is repeated again (usually twice more) to keep the yeast action continuous until the dough is soft and pliable enough to be sheeted and moulded without tearing or sticking.

The three punches follow a typical time pattern, the time elapsing to the first punch taken as 60 per cent of the total fermentation time, with 30 per cent allocated to the second punch and 10 to 15 per cent remaining before the dough is ready for makeup.

Sponge and Dough Mixing Process

The sponge and dough method of mixing is preferred in the majority of plants because of greater flexibility of control for fermentation and machine makeup, as well as better adaptability to mass production schedules. The principle involved in the sponge and dough process is that of mixing a part of the flour and certain other ingredients into a fairly stiff dough, called the sponge, and allowing fermentation to proceed, usually three to four hours, until the gluten of the sponge has become well conditioned into a soft, weblike structure containing a large volume of gases. These gases, air and water vapor together with the carbon dioxide and alcohol vapor produced by fermentation, will have increased the volume of the original sponge many times. The mass is allowed to rise until the extensible limit is reached and the sponge "drops." This should be about 65 to 70 per cent of the total time the sponge is allowed to ferment. The sponge may contain anywhere from 50 to 80 per cent of the flour, with yeast, yeast foods, shortening and some of the sugar. The percentage of water used in the sponge is less than the total amount for the complete sponge and dough. The amount used depends upon the absorption value of the flour in the sponge and the degree of firmness desired in the sponge.

Fermentation time will depend upon the hardness, or strength of the flour and the per cent of flour in the sponge. Temperatures, as always in fermentation, are important. Sponges are usually set at a cool 75° to 78°F., and allowed to ferment in the fermentation room in an atmosphere conditioned to a temperature of 80°F. and relative humidity of 70 per cent.

When sponge fermentation is judged to be complete, the sponge mass is returned to the mixer, the balance of ingredients in the formula are added and the whole mass again mixed, at high speed, for only a few

minutes until the new dough appears smooth and pliable. Mixing time for the dough stage will depend upon the per cent of flour used in the dough stage and its strength, but will have a great effect on the condition of the final dough for machine makeup. The combined, remixed sponge and dough is then allowed to ferment for 15 to 30 minutes in the dough trough to relax and expand, ready for machine makeup into loaves.

It should be understood that two or more flours, especially a strong and a weak flour with dissimilar gluten characteristics, cannot be blended into one average flour with homogeneous fermentation and baking properties. The proteins (glutens) of the two flours as well as their starches will each demonstrate their own fermentation rate and dough characteristics. The finished dough, and the bread from such blends, will therefore be a compromise between the two. In some cases the product of such blends, by the straight dough process, may be more desirable than that of either alone. It is not unusual for straight doughs made from some types of "general purpose" flour to exhibit these diverse flour characteristics to a striking degree.

The sponge and dough method, however, provides for the more efficient handling and combining of two different flours, such as a strong hard northern spring wheat flour in the sponge, and a southwestern winter wheat flour in the dough stage, each used for its own characteristics of baking strength, volume and flavor.

Wide variations in percentages of flour and other ingredients, and their addition to either the sponge or dough stage, are possible in the sponge and dough process, depending upon the character of the flours and the desired doughs for machine makeup and baking. Due to the repetition of mixing and fermentation, corrections for errors, adjustments for delays, changes in schedules or other variables can be compensated for at several points in the process. It is this wide flexibility that accounts for the greater popularity of the sponge and dough method.

Critical Factors

The speed and length of time doughs are mixed at high speed affect the softness and extensibility of the gluten, so that the continuing and subsequent action of yeast fermentation can complete the hydration and conditioning of the gluten to just the right degree for best machine makeup and baking.

Time and temperature also become critical factors at every point in the mixing and fermentation processes, along with the added factor of pH (acidity), because they control the rate of enzyme actions in the dough, and the aerating action of the carbon dioxide gas and alcohol produced by the yeast metabolism.

While the action of bacteria (particularly that of the lactic acid formers) in the ingredients and doughs cannot be entirely disregarded, because of their effects on acidity and flavor, their consideration is not justified in this discussion.

Fermentation

The object in dough fermentation is to generate sufficient gas for maximum aeration and to condition the gluten and soften the colloidal struc-

Courtesy of Union Steel Products Co.

FIG. 63. BAKERY FERMENTATION ROOM

A typical wholesale bakery fermentation room provides for controlled flow of air at a specified temperature and humidity.

ture so that the optimum amount of gas is retained. The yeast cells, uniformly dispersed throughout the dough mass, act upon the available sugars, transforming them into carbon dioxide and alcohol. Lactose (milk sugar) cannot be used by the yeast, and maltose generated by the action of amylases on starch is utilized more slowly than sucrose, fructose, or glucose. The carbon dioxide gas, set free in the tiny air cells of the dough, expands and raises the dough to several times its original volume. At the same time the gluten structure holding the mass together becomes more elastic, forming retaining walls or membranes around the gas and air cells, expanding with the increasing volume. Yeast multiplication

does not occur in dough to any appreciable extent because the conditions are not suitable.

The biochemistry and physics of the fermentation process, involving as it does a complicated energy system, cannot be discussed here. The result of all the reactions occurring during the fermentation is to mellow and condition the dough ready for machine makeup.

The fine balance between formula percentage of ingredients, mixing times and fermentation of the doughs requires an expert knowledge and experience of these factors in terms of the flours used and the character of finished product desired. Experience, therefore, based upon a thorough knowledge of the basic principles involved in these complex and interrelated actions, is required to meet the rigorous demands of mass production in the modern mechanized baking factories. Thus the bakery production supervisor of the future must be trained in the sciences involved in baking, which can best be accomplished at the university level, in undergraduate and/or graduate school courses designed to give a broad background of the basic sciences.

MAKEUP MACHINERY

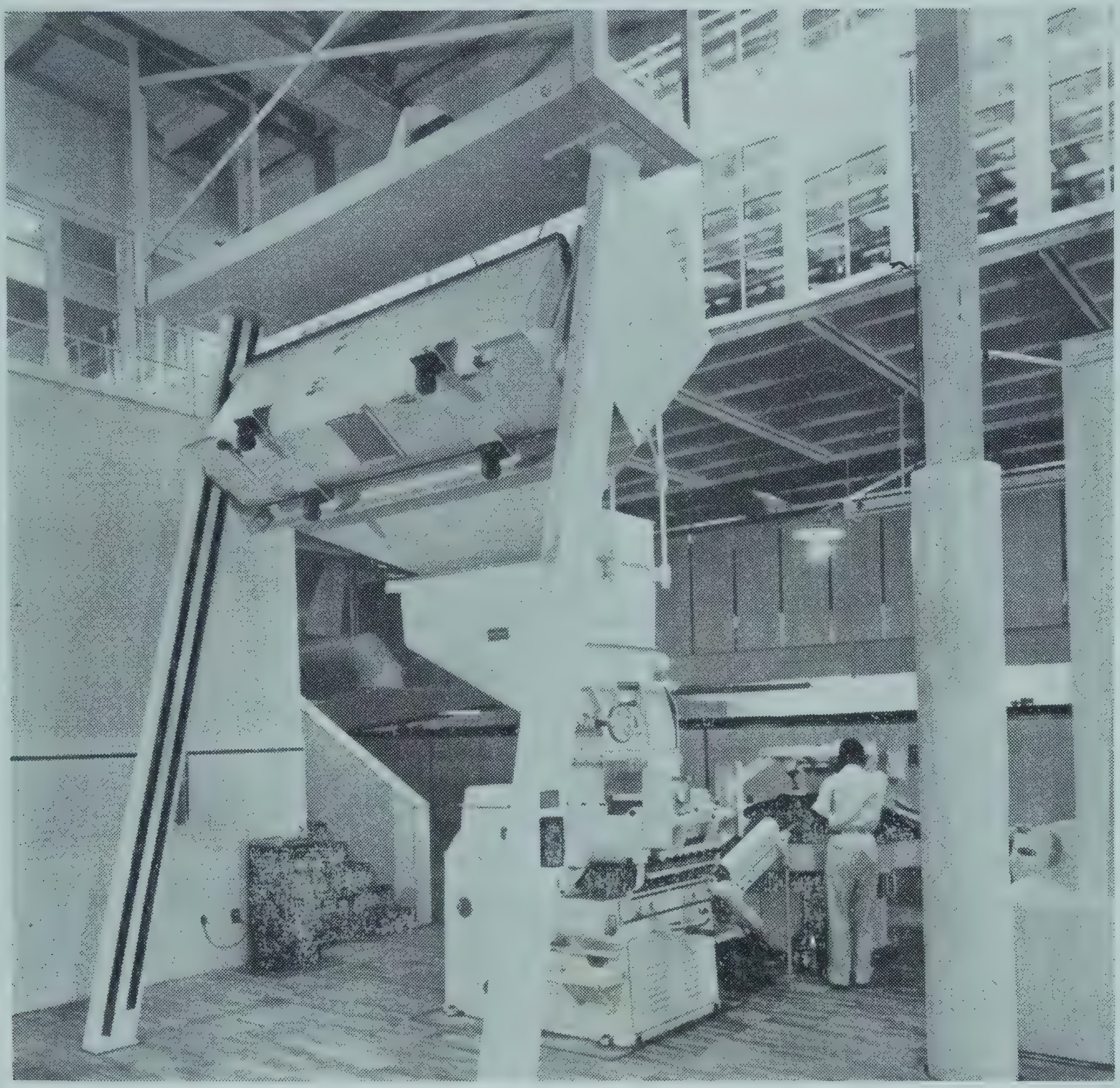
The familiar hand operations such as kneading, shaping and panning of dough pieces sized to make individual loaves, are now performed by machines at speeds of 35 to 120 pieces per minute. It is conceivable that there are limits beyond which the speeds of machines may not go in altering the shape and density of the colloidal system which is the dough piece, without irreparable damage to the structure that has been so carefully developed by fermentation. So while bakery machine speeds have been steadily moved upward, excessive damage to the dough and the resulting bread structure have caused bakery operators in some instances to slow them down again. This same argument, in reverse however, seems to be a factor in the almost instantaneous breakdown of gluten strength to produce a very fine grain and texture in the Baker Do-Maker and similar continuous mix processes (Parker 1957).

Dough Divider

In the conventional bakery operation, the fermented dough is automatically separated into pieces for specific loaf size by the divider, a machine which collapses the dough by pressure and shears off unit portions on a volumetric principle. The divider has been aptly characterized as the cash register of the bakery, for dough piece weights need to be accurate and uniform within small fractions of an ounce to prevent loss from overscaling or danger of underweight loaves from underscaling.

The divider discharges the scaled dough pieces onto a moving belt

from a series of pockets for transfer to the rounder. Speeds of 12 to 20 cuts per minute are considered most suitable for normal doughs, so that an eight-pocket divider will deliver 120 scaled pieces per minute. There is provision for quick and easy adjustment of the size of the pockets for



Courtesy of Baker Perkins Co.

FIG. 64. ILLUSTRATING HOW THE TROUGH ELEVATOR EMPTIES THE DOUGH INTO THE DIVIDER HOPPER

From the 8-pocket divider the separate loaf-size dough pieces are transferred automatically to the rounder (rear) and on into the intermediate proofer.

control of scaling weights of the dough piece while the machine is running. The divider is also equipped with variable speed control and adjustment for controlling the pressure exerted on the dough as it is forced into the pockets.

Rounder

The rounder is an intermediate, but important machine which rolls the dough piece into a ball. As the piece travels around the circumference

of a cone, the tension of friction against the grooved surface stretches the skin around the dough as in hand rounding. This smooth skin surface helps to retain the fermentation gases as the dough recovers its lightness. The dough pieces are then transferred by belt to the automatic feed at the intermediate proofer and dropped into depressions in trays of wood, metal or canvas.

Intermediate Proofer

The principle of the intermediate proofer is to allow the dough pieces to recover from the punishment received in the divider and resume fermentation for 8 to 15 minutes to the point where the dough piece is again soft and pliable, ready for moulding into loaf shape.

In construction, the trays carrying dough pieces ride continuously on chains that carry the trays up and back and forth in an enclosed cabinet until the dough pieces are ready for the moulder. The dough pieces are discharged from the trays by the simple expedient of turning each tray over and dropping the dough piece onto a moving belt that discharges them into a guide chute at the top of the moulder. Total time in the intermediate proofer is controlled by means of variable speed drive.

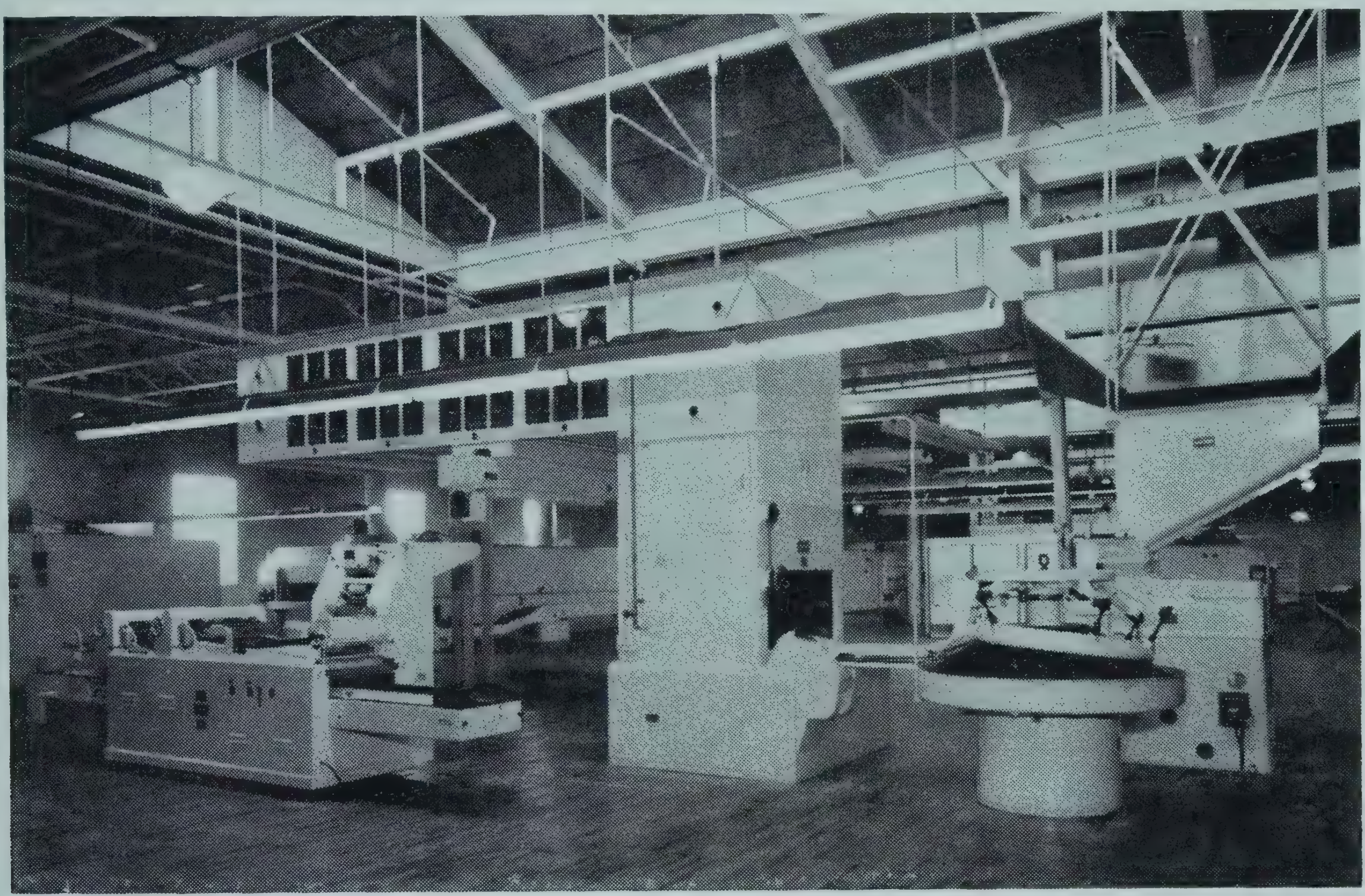
Moulder

Here again, the principle of the moulder is to do by machine at high speed the arduous and skillful flattening, curling and sealing of the dough piece formerly done by hand. The moulder therefore is equipped with two sets of rolls. The top set, or sheeting rolls take the dough piece as it is delivered automatically from the intermediate proofer, flatten it out to about three times the diameter of the original piece while squeezing out most of the gases. From the head rolls the flattened dough piece, from one-fourth to one-half inch in thickness, depending upon the weight and size of the piece, is then curled or rolled up into loaf shape by means of a set of curling rolls. This dough cylinder is rolled under a flat canvas surfaced sheet of metal called a pressure board to elongate it and seal the outside edge. The squeezing action produces a more uniform distribution of gas cells so that proofing in the pan results in better grain and texture in the loaf.

Modifications of the curling action have been developed in an attempt to produce a more uniform density of dough throughout the curled and sealed dough piece. Some of these are designed to turn the flattened piece from the sheeting rolls 90 degrees, or 180 degrees, and then curl them by means of a flexible chain mat. These modifications are known as cross-grain moulding or reverse moulding. Settings of the sheeting

rolls (head rolls) are the critical stage in moulding and therefore these rolls must be adjustable for requirements of different doughs.

Two main difficulties of machine makeup are the fact that the machine cannot "feel" or react to the natural tenderness of the finished, fermented dough piece, and has to be adjusted to the right tension or force to prevent "killing" the dough. Teflon surfaces are now used at some points where the iron or steel comes in contact with the dough, to prevent sticking and reduce the need for dusting flour. Another handicap is the neces-



Courtesy of Baker Perkins Co.

FIG. 65. THIS ARRANGEMENT OF BAKERY MAKE-UP EQUIPMENT PROVIDES FOR THE AUTOMATIC MOVEMENT OF DOUGH PIECES

They pass from the divider (right) through the rounder, intermediate proofer (center), into the automatic reverse-sheeting loaf moulder and panner (left). The moulded and panned dough pieces then move into the proofing room to rise in volume preparatory to baking in the automatic traveling hearth oven (left rear).

sity for the use of dusting flour, or starch, to prevent sticking through the machines. This raw, unfermented dusting flour has a tendency to tighten up the dough structure and frequently shows up as hard pills, ridges or even cores in the finished loaf.

Up to the pan, every operation of machine makeup should be carried out in a suitable temperature and humidity. The air conditioning of large plant areas in the bakery, however, presents difficult problems of power cost and control, and most bakeries provide for temperature and humidity control only in the more critical areas of fermentation and in final proofing.

They depend upon natural or forced ventilation to help equalize temperatures in the working areas.

Proofers

Once the shaped dough piece is in the pan, where it is placed by hand or dropped automatically by machine panners, the operation is ready for completion by the final proofing, or pan proof. The greased or coated pans containing the formed dough pieces are moved into a proofing room, cabinet or enclosed area where the fermentation action is again stimulated by heat at a temperature of 95° to 98° F. in a relative humidity of 80 to 85 per cent. At this temperature and humidity, fermentation action is at nearly maximum rate so that the dough rises uniformly in the pan to the point just above the pan top where the oven heat of baking will produce the loaf of desired shape and size with the best interior and crust quality. This final proofing operation requires from 40 to 60 minutes with normal doughs and must be accurately judged for best baking results. The high relative humidity is maintained in proofing to prevent drying and crusting of the loaf top surface so that the dough rises freely in the pan.

The trend toward automatic operation throughout the baking process has led to the development and engineering of continuous proofing mechanisms in which the panned dough piece from the moulder is carried through the final proof under controlled conditions and speeds to the mouth of the continuous oven where the pans are transferred automatically to the oven shelves for baking.

Ovens

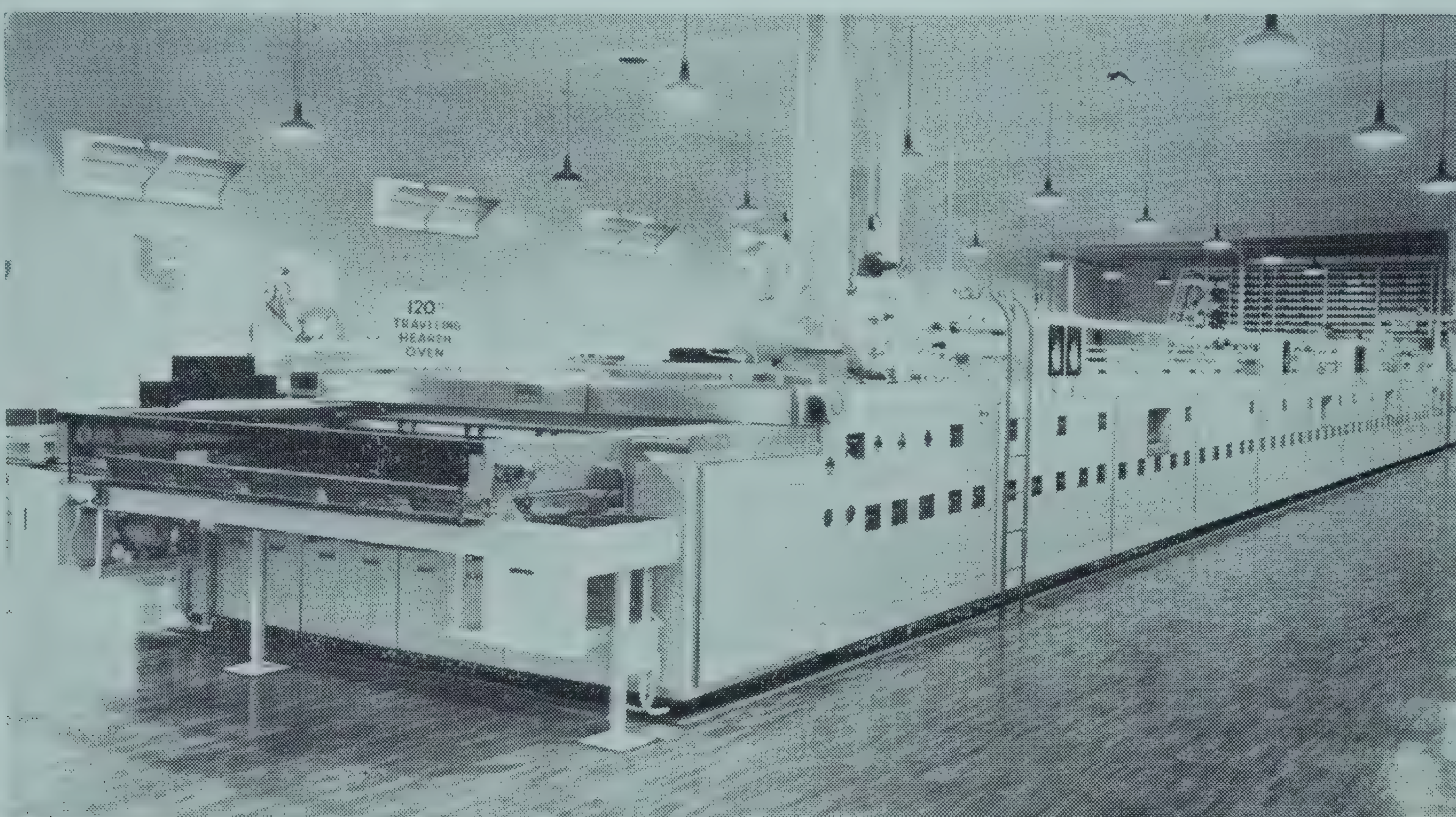
When all of the sequence of operations have been carried out under controlled conditions of temperature, time and humidity, and depending always upon the type and baking characteristics of the flours used, the proofed dough piece in the pan is ready for the final and most important phase of baking. In the oven a soft, tender but unpalatable dough piece is transformed by heat into a light, porous, appetizing and nutritious loaf of fresh baked bread.

Regardless of the type of oven, whether stationary hearth, moving tray, or traveling hearth, the baking process is much the same. Heat is applied at a steady rate, usually from 400° to 500° F. for a period of from 20 to 30 minutes, depending upon the type, shape and size of the product to be baked. Denser doughs for rye breads or other special types require the highest range of temperature and a little more time. The presence of high residual sugar content and more milk solids will require lower baking temperature to prevent excessive carmelization and darkening of the crust.

Part of the heat in the oven is applied to the loaf by conduction

through the pan, part by radiation and convection to the surface of the loaf above the pan. The heat supply, both top and bottom, must be steady.

The many changes that take place rapidly in the setting up and baking off of the loaf are not too well known because of their complexity and speed. In an effort to picture them in more or less sequence, we may characterize the first step as that of "oven spring" where the heat rapidly expands the gases held in the myriad of cells. Dissolved carbon dioxide and alcohol are vaporized to increase the internal pressure, and these



Courtesy of Baker Perkins Co.

Fig. 66. A View of an Automatic Loading and Unloading 120 Foot Traveling Bakery Oven and Automatic Bread Depanning Machine

The baking bread moves through the oven on steel trays to the end where the pans are automatically discharged and conveyed to the depanner. Emptied pans are returned by conveyor to the moulder-panner as they cool and the freshly baked loaves are sent to overhead conveyors for cooling in readiness for slicing and wrapping.

along with the added pressure of moisture vapor all help expand the loaf to approximately twice its original size, until the crust is sufficiently set to hold the shape and the baking is completed. During that interval moisture is released from the loaf and helps to delay the hardening of the crust until the new loaf shape has been formed. In the case of some breads, particularly rye breads where a glossy crust is desired, additional steam is introduced into the oven during early minutes of baking. The use of steam at low pressure and sufficient volume in the oven is an important factor in producing a better volume and a more tender crust.

During this early baking or oven spring period, the biological activity of the various enzyme systems of the flour, yeast and any other added

enzyme supplements, are carried past their optimum range, then arrested and destroyed by the increasing temperature in the loaf.

As the temperature continues to rise, the soft, pliable colloidal system of gluten proteins, dextrins, sugars, and fats is denatured, stabilized or fixed by heat and by the removal of much of the free moisture. The starches absorb more water and swell to larger size in their entrapped position within the gluten framework. These starch softening and swelling properties become active at about 130° F., while the gluten structure begins to coagulate and set up about 165° F. and continues until final baking temperatures of near 212° F. are reached. The fats (shortening) have been melted in the baked structure and tend to coat the walls of the rapidly expanding cells, to reduce the cell-wall porosity and help maintain uniform fineness of cell structure.

Just how far the fundamental conditions of time, temperature, pH and the speed of biological processes now considered essential to the conventional methods of bread production can be altered and speeded up, remains to be seen. After thousands of years of empirical procedure, followed by a relatively few years of scientific study, modern science holds promise of accomplishing about the same results in a fraction of the 4 to 8 hours now utilized to make and bake a loaf of bread.

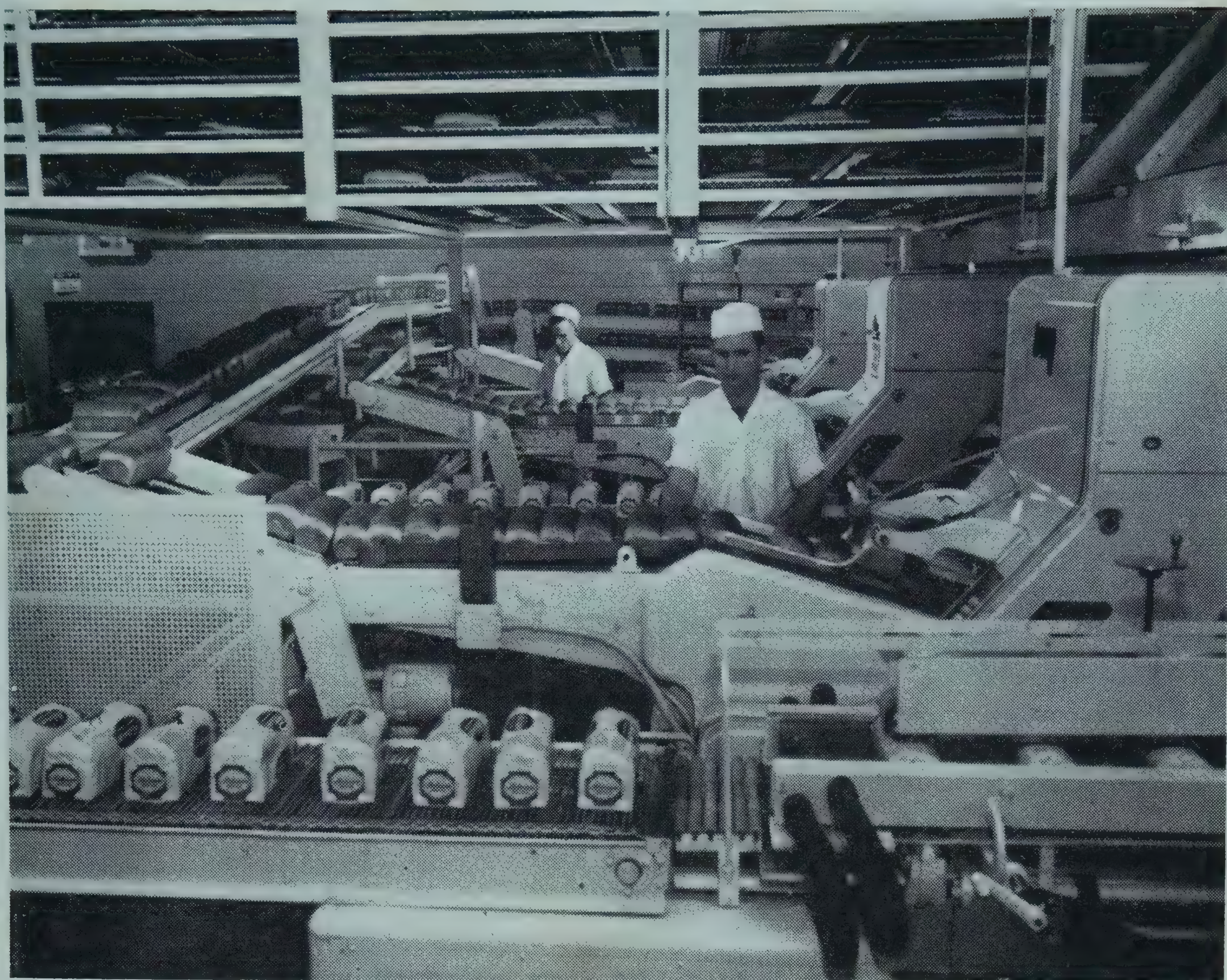
One thing is certain, that much more fundamental research and study of what takes place in the bread baking process is necessary before we can hope to further our knowledge and understanding, and therefore our control, of such time saving procedures.

COOLING, SLICING, AND WRAPPING MACHINERY

When the great convenience factor of sliced bread was added to the industry's service about 1928 to 1930, a new group of problems had to be worked out. The principle of slicing the loaf with a set of parallel steel blades spaced one-half inch apart and moving at high speed, has remained much the same. Reciprocal, up and down motion of alternate blades has been replaced by a series of band blades. Many variations in cutting edge of the blades or bands have been tried, from eighth inch scallops with sharp pointed edges to half-inch or more spaces between slicing edges.

The first slicing machines were slow, with a tendency to crush the loaf as it was pushed through the blades by the loaves behind it. There was a great deal of crumbing, due to the high speed tearing action of the cutting points. Greater tenderness of crust was desirable, and the loaves had to be thoroughly cooled to about 90° F.

More recently, it has been found that with improved slicing-cutting edges on the band blades, the high band blade speeds of 1000 to 1500



Courtesy of Baking Industry

FIG. 67. BREAD SLICING AND WRAPPING MACHINES

Batteries of several slicing and wrapping machines operate continuously to handle the loaves as they come from the cooling conveyors overhead.

feet per minute could be reduced to as low as 400 feet per minute, with better, cleaner slicing, and at bread temperatures only slightly reduced from the oven. This has likewise increased the speed of slicing.

The problems presented by the machine wrapping of sliced bread were difficult of solution. Improvement in machine design, with the application of heat sealers for self sealing wax paper or cellophane, cooling plates for fast setting of the sealed edges and ends, the changes in the wrapping materials themselves, all contributed to a firmer, more protective package that would stand the handling of delivery and in-the-store traffic.

Provision is made for adjustment of both slicer and wrapper to different sized loaves. Wrapping machines are now operating at speeds up to 120 loaves or more per minute, and are synchronized with the slicing machines so that the operation is continuous. Batteries of several of these combination slicing and wrapping units can provide for a continuous flow of finished breads as fast as they come from the oven.

NEW PROCESSES

Now that the so-called "brew" process and "continuous mixing" methods have been recently developed within the baking industry, mostly by trial and error method of experimentation, we have further complicated the picture of what takes place within the dough. Here again the imposition of severe mechanical action on the gluten structure and the addition of an active yeast ferment developed outside and separate from the dough, have produced modifications of grain and texture in the loaf and significant changes in the flavor that were always heretofore associated with the older or traditional bread making process.

From long experience in the effort to control many variables in regular dough fermentation and makeup, it would seem logical to expect that the bakers' failure to control accurately the "continuous" or "brew" process will again await the necessary research into a new order of reactions that take place.

STALING OF BREAD

Bakers bread is recognized as a perishable product, fresh when just out of the oven but starting to age, firm up and become progressively stale thereafter. The staling process represents a series of slow changes that can be retarded somewhat by suitable ingredients, proper packaging, and temperature control, to keep the loaf fairly soft and satisfactory in flavor through the second and into the third day. Third day freshness has in fact become a necessity with the system of delivery used by the wholesale baker.

The location of the loaf on the retail grocers shelf while awaiting purchase by the consumer may extend the time interval from oven to table by 18 to 36 hours or more. The baker's removal of any unsold bread from the store after the second or third day becomes one of the most serious economic losses in the baking industry. Even more important is the danger of disappointing the customer with a stale loaf.

Studies of the physical and chemical changes involved in staling have occupied the research of many scientists in the fields of cereal technology and food chemistry for years. Their objective was to find a way to prevent staling or retard it to the point where the baker could bake bread for inventory, with an assured shelf life of several days to a week. An extension or improvement of even 24 hours would be of great economic value.

While agreement is lacking as to the most important changes in the staling of bread, we can mention those changes brought out by investigations to date.

Staling of the crust as distinguished from the interior crumb is of

greater significance in the unsliced loaf. The crust came from the oven dry and crisp. It changes slowly with the transfer of moisture out from the interior of the loaf, and with the absorption of water vapor from the surrounding atmosphere, until it finally becomes tough and leathery.

Slicing and wrapping the loaf while warm helps to facilitate the rapid change of moisture distribution between the crust and crumb and the atmosphere immediately surrounding the loaf within the wrapper.

Staling of crumb is attributed to physiochemical changes within the starch and dextrins present (Geddes and Bice 1946, Pyler 1952). These changes occur only above a certain moisture content, but in the normal loaf of white bread the moisture is sufficient to promote the transformation of the amorphous structure of the starch into a more crystalline form with attendant firming of the structure. Higher temperatures slow down the staling rate, and may reverse the staling process to some degree, accounting for the fact that the brief reheating of the loaf in the oven has the apparent effect of freshening it. Upon cooling of the reheated loaf, however, the staling proceeds more rapidly than before. The flavor of bread that has staled to a considerable extent cannot be improved by reheating.

Quick freezing of the loaf will arrest staling until it is again thawed, but after thawing, staling resumes and appears to proceed at a faster rate than in unfrozen loaves. Likewise the temperature changes that take place in the handling of wrapped bread in delivery to the stores in cold weather, with subsequent changes in the store and to the home, all help to deteriorate the natural freshness and flavor of the fresh loaf. Some baking companies have resorted to heated delivery vehicles to maintain more favorable temperatures of 70° to 80° for winter time deliveries in colder climates.

Thus staling of bread is an added control factor to the many already encountered in the detailed production of the product, and one which is therefore urgently in need of solution through further research.

MANUFACTURE OF BUNS AND ROLLS

The almost universal popularity of the hamburger and the hot dog in all their variations, combined with the trend toward picnics and outdoor cooking, have led the production and sale of buns and rolls into the realm of big business. Many a baking company has found the bun and roll business an important part of their total sales volume.

The mass production of buns and rolls has been greatly facilitated by the design and use of specialized machinery. The trend now is the

combination of such equipment in a sequence that makes the production continuous and practically automatic.

Bun and roll doughs follow the same general principles as for bread production. The smaller unit size, shape and sweeter flavor, and the makeup of the extruded dough pieces at high speed, have imposed modifications that require the mixing of special doughs. These doughs when fermented are placed in the hopper of the roll machine, and subjected to pressure that extrudes small dough pieces weighing roughly one to two ounces.

A sequence of rounding, panning into special bun or roll pans and final proofing prepares the buns or rolls for baking at about 350° to 450° F. for 8 to 12 minutes. Baking is carried out in special traveling tray ovens or reel ovens, or they can be handled automatically in the traveling bread oven that is run at higher speed and lower temperature than for pan bread. Automatic dumping equipment for bun pans from the oven operates to deposit the buns on a traveling belt or conveyor for cooling.

Automatic bun slicing machines can be used to cut the bun or roll into two halves before they are packaged more or less automatically in a suitable number of units. Standard wrapping machines are used that will handle buns or rolls nested in trays and overwrapped with cellophane or semi-transparent waxed paper. Some wrappers will handle the stacked buns without any supporting paperboard tray. These packages facilitate the distribution and sale of buns and rolls in convenient quantity from the same display space in the stores as breads and other baked products.

BROWN AND SERVE ROLLS

The marketing of "brown and serve" rolls has developed phenomenally within the past ten years. Rolls, singly or in clusters, are baked just enough to reach the final volume and stable conditions within the roll, but not enough to complete the browning of the crust. Baking is carried on for about 20 to 22 minutes at a lowered oven temperature of about 285° F.

The rolls are then packaged in protective paperboard trays or boxes with transparent wrappings, and distributed to the store outlets much like other baked products. Refrigeration is not necessary, but is helpful in maintaining the products in good condition. The consumer merely finishes the baking procedure in the home oven at 350° to 450° F. for a few minutes to give the hot rolls the desired crust color and freshness appeal.

A great deal of research and experimentation has gone into the development of suitable wrapping materials for baked products, to provide

both sanitary protection and color printing for identification of the manufacturer's brand name. The principles of package design, materials, colors and consumer interest would require another volume to be explained fully.

SWEET YEAST RAISED PRODUCTS

The sweet baked products such as sweet rolls, coffee cakes and Danish pastry are special modifications of the yeast raised dough process. In practice, the sweet doughs are much richer in sugar and shortening, usually contain eggs, and ferment faster. The fermented dough needs to be made up into suitable shapes and sizes, with or without fillings or toppings, and proofed carefully so as to bake out while retaining their characteristic shape and form. Their size, shape, and variety of flavors, fillings and icings, are limited only by the bakers technique and imagination. Most of these sweet dough products are especially appetizing when made up by hand, and therefore do not lend themselves easily to large volume machine production.

COMMERCIAL CAKE MANUFACTURE

There are three general or basic types of cakes: (1) Layer Cakes, such as White Layers, Yellow Layers, Chocolate Layers and Devils Food Layers; (2) Pound Cakes; and (3) Foam Type Cakes, such as Angel Food, Sponge Type Cakes, and Chiffon Cakes.

In contrast with the complexities of the bread making process, the baking of cakes presents a fairly simple set of principles. Instead of yeast fermentation, chemical leavening agents such as baking powders are utilized to furnish the necessary amounts of carbon dioxide gas at the right time in the cake baking process. Since little or no gluten development is needed or desirable, the process lends itself to rapid batter mixing, depositing, and baking.

Cake Ingredients and Their Functions

Flours best suited for cake work are milled from soft winter wheats that contain a relatively low percentage of protein. A general specification for a fine cake flour would be a finely milled, high patent extraction soft winter wheat flour with not over 7 to 8 per cent protein and a low ash content of about .34 to .38 per cent. The flour should be thoroughly bleached, with a pH value of 5.0 to 5.3 and have a fine uniform granulation. Flour is the chief component of the cake structure.

The shortening used plays an important role in cake production. The most important function is that of carrier for the air cells that are en-

trapped during the creaming stage of batter mixing. Shortening, because it is used in generous percentage, has an important lubricating action, especially during the turbulent movement of melted fat through the mix of gluten and starch during early stages of baking, when it facilitates the great expansion of air cells containing moisture vapor and carbon dioxide gas to make a light, tender texture.

The cake making process has been greatly simplified by the introduction of special emulsified shortenings that hold larger quantities of liquid and yet give more stable batters that yield a finished cake of larger volume and longer lasting softness.

Shortenings for cake work may be of several types, partially hydrogenated vegetable, or animal fats, or blends of several of these to a soft plastic consistency at normal working temperatures of 68° to 78°F. Antioxidants may be used to stabilize the finished fat and prevent rapid development of rancidity in storage. The characteristic behavior of these emulsified shortenings depends upon their careful preparation and tempering to obtain the proper crystalline structure. Storage temperatures above 90°F. will denature the structure balance within the shortening and greatly decrease the cake making value.

Fresh creamery butter, so highly prized for its rich flavor in cakes, may still be used in high proportion of the total shortening with aid of suitable emulsifiers. All-butter cakes of superior quality and appetite appeal are now on the market. General practice however is to use part shortening and part butter, or the butter may be replaced wholly or in part by the new margarines with their good butter flavor and built-in emulsifying properties.

Eggs are also a basic ingredient in cake and have several well known functions, such as a binding action and a structural stabilization, and a leavening action, and the lecithin in the egg yolk has an emulsifying action in the batter. They carry an important flavor factor and color as well as a high nutritive value.

Eggs are used in several forms, as fresh or frozen whole eggs, or, separated into yolks and whites for use in certain types of cakes. Dried eggs, in powdered form, either whole egg whites, or yolks, are now available in suitable form due to modern processes of preparation and packing.

Eggs are the most costly ingredient in cake mixing and should be used to advantage within the limits of their best formula percentage.

The sugars used in cake baking are important contributors to flavor and texture. Cane or beet sugar of medium sized crystal structure is a basic ingredient, for it is the sharp edges of these crystals that help cut air into the fat during the first, or creaming stage of building the batter.

Sugars and syrups of various kinds are also used in quantity in the preparation of several different types of icings.

Formula Balance

Batch mixing of cake batters for layer type cakes has been in general practice for many years, with many variations in the actual procedure due to bakers' individual success with different techniques. Extensive experimentation and microscopic study of batters (Carlin 1944) has supplied knowledge that narrows the process down to a few basic principles and enables the operator to judge with considerable accuracy the proper formula relationship of ingredients and best sequence of mixing technique.

In the layer cake formula, for example, each ingredient has a major purpose or function, and consequently the results depend upon the proper balance of these functions. These ingredients act as:

(1) Tougheners—Flour and milk solids.
(2) Tenderizers—Shortening, sugar, egg yolks, and leavening agents.
(3) Moisteners—Liquids and the moisture content of eggs.
(4) Driers—Flour, sugar, dry milk, and cocoa.
(5) Flavorers—Sugar, chocolate, salt and flavoring materials added as such.

Some variation or adjustment of ingredients is possible, so long as the general over-all balance of these functions is maintained. Consequently when one ingredient is changed, for example the amount of flour which acts as structural toughener and drier, it is necessary to compensate for that function by a corresponding change in tenderizing ingredients and the liquid or moistening ingredients. These adjustments are found to be possible only within certain limits which are known as the formula range for each type of cake.

A typical yellow layer cake formula range can be expressed as follows.

Yellow Layer Cake
Formula Range

	Formula Weight, Per cent
Flour (Cake)	22. – 23.
Salt	0.5 – .75
Shortening	8. – 11.
Skim Milk Solids	2. – 3.
Baking Powder	1.25– 1.25
Egg (Whole)	10. – 14.
Water	24.5 – 22.5
Sugar (to make 100 per cent)	31.75– 24.5
	100.00 100.00

The "water factor" in the above formula is 30 to 33 per cent and includes the water added as such, or as liquid milk, plus the moisture content of the eggs used. Frozen whole eggs contain about 74 per cent moisture.

A similar formula range holds true for white layer cake, except that egg whites are used because of lack of yellow color. Up to two per cent of whole egg can be used without noticeable color change. Since egg white contains mostly albumin protein, it has less structural strength than whole egg, and therefore needs to be used in somewhat larger percentages, or 12 to 16 per cent. The egg white also contains more water than whole egg or egg yolk, so the added liquid is reduced in the white cake formula.

When cocoa is used in devils food cake for example, less flour is used to compensate for the toughening action of the 4 to 6 per cent cocoa. Chocolate adds tenderizing action by virtue of its higher fat content. The formula balance concept may be carried over to each type of cake when the ranges of ingredients have been established by careful laboratory study.

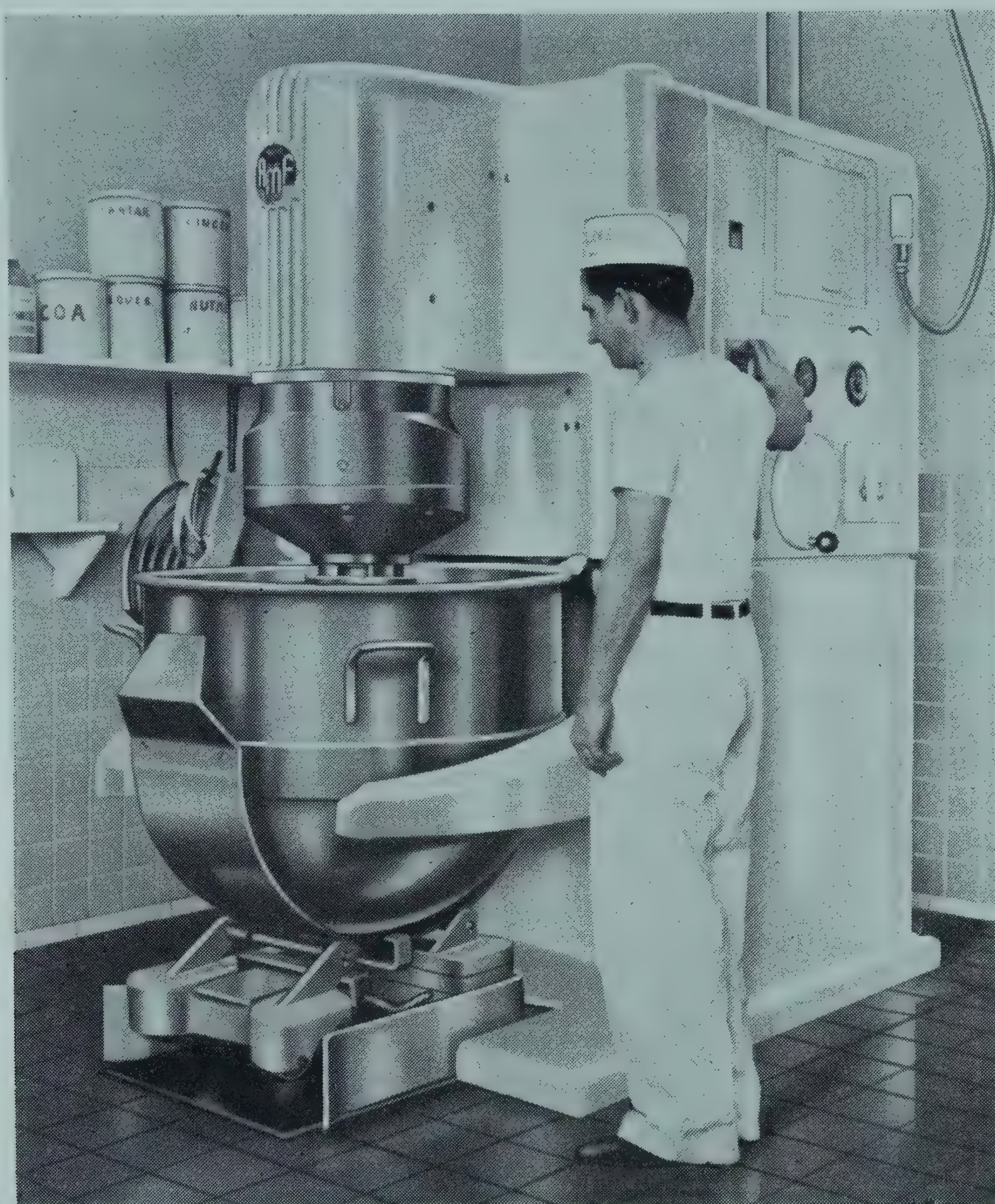
Mixing Cake Batters

The critical factor in batch mixing for layer cake types is aeration. The objective is to get a maximum incorporation of air in the fat. Flour that has been well aerated by thorough sifting, along with dry milk and baking powder, sugar and shortening are placed in the cake mixing bowl with approximately 15 to 16 per cent of the liquid. Mixing is started at low speed for 1 to 2 minutes and continued at second or medium speed for another 4 to 5 minutes. Care is taken to use enough water to begin hydration of the flour and promote a homogeneous mass, but not enough to dissolve much of the sugar, because the sugar crystals aid in cutting air into the mass for retention in the fat. Repeated sifting or aeration of the flour before mixing helps greatly in carrying more air into the mixing mass.

The temperature is important and should not be allowed to rise much above 72° to 80°F. during the first or creaming stage. Similarly, best mixing results will be obtained where the finished batter does not exceed 70° to 72°F. The finished batter temperature is easily controlled by adjusting the temperature of the eggs and water used in the batter stage of mixing. The temperature coefficient of friction in the mixing process is also taken into account in temperature adjustment.

The mixing is completed by the addition of the eggs, and their thorough incorporation in several parts, with final addition of the remaining water and flavoring. Mixing is continued at medium speed for another 4 to 5 minutes, scraping down the bowl to make sure of thorough distribution of the sugar or batter in the bottom of the bowl, until the finished batter

is smooth and homogeneous. Excessive beating or high speed agitation will not increase the aeration in the shortening but only serve to beat out part of the air already entrapped in the mix.



Courtesy of American Machine and Foundry Co.

FIG. 68. BATCH MIXER FOR CAKE BATTERS SHOWN HERE HAS A BOWL CAPACITY OF 340 QUARTS OF BATTER

Rapid proximate measurement of the specific gravity near completion of the mixing will indicate the proper degree of aeration and serve to check against the uniformity of successive batches.

Continuous Cake Mixing

In contrast to the conventional batch mixing methods described above, a new mechanical system of rapid mixing has been developed and is widely used for continuous large scale cake production.

In place of the creaming stage and secondary mixing procedure, all

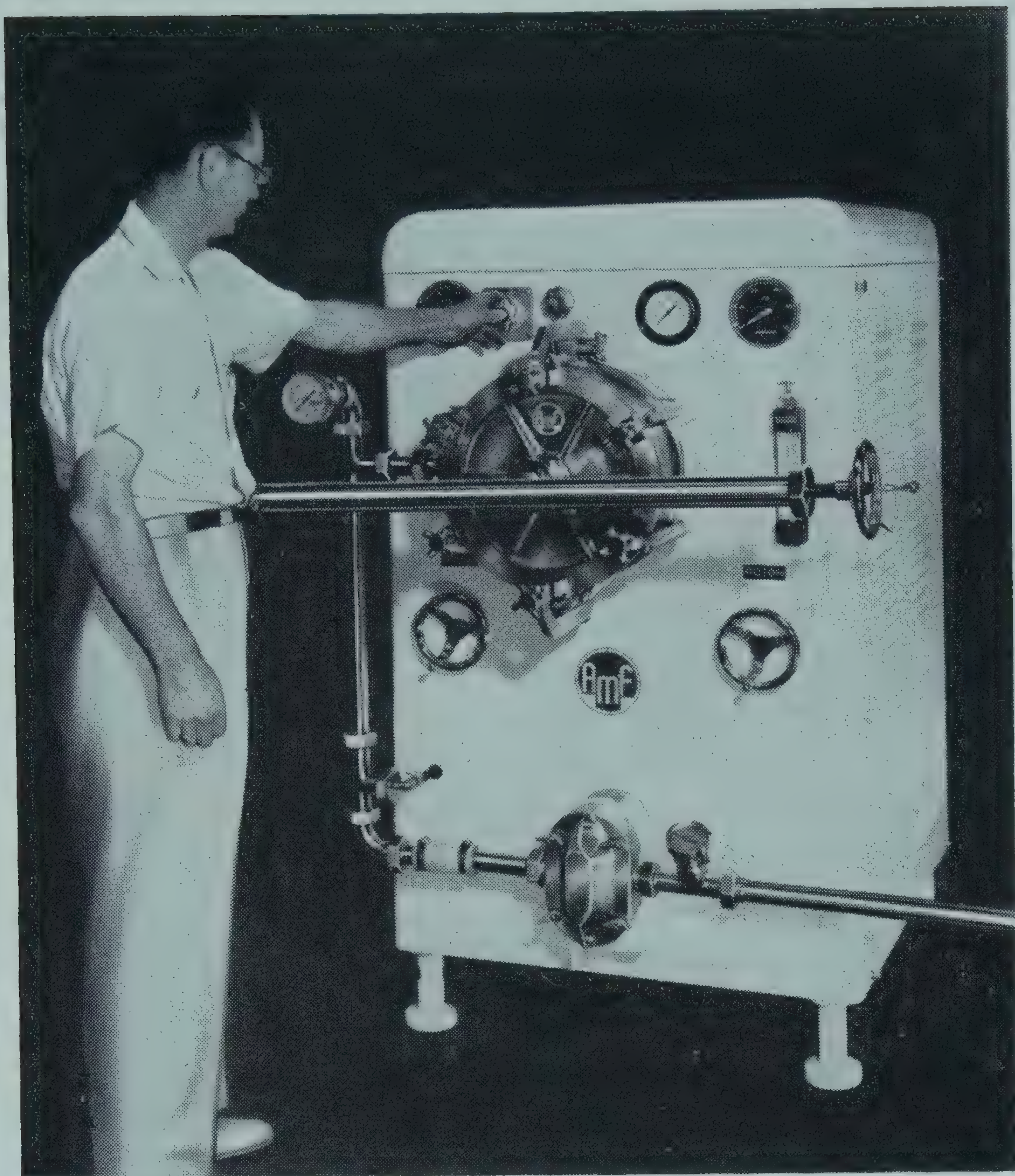
ingredients are placed in a mixing bowl and mixed only to a homogeneous slurry. This preliminary mix is pumped directly to the emulsifying type of mixer, with a stream of air under pressure. The high speed action of the mixing rotor forces the air into the batter in fine bubbles and the batter is then flowed directly into the depositor for panning and baking. Almost any type of cake can be produced by this method, with characteristics of greater stability, uniformity and fine cell structure. It has facilitated continuous production of angel food and sponge type cakes and is valuable in preparing such products as marshmallow cream and other fillings and toppings.

Baking

When mixing is completed, the cake batter is deposited in suitable pans that have been prepared with treated paper or grease to prevent sticking, and baked immediately at a temperature of about 350°F. for approximately 20 minutes.

As the temperature of the batter rises, the fat is melted and the carbon dioxide gas is released by reaction of the baking powder. Combination type baking powders are used that give up their gas only after temperatures have risen to considerably above room temperature and the cake structure is ready to accommodate the rapid leavening action. The increasing pressure of the carbon dioxide and water vapor in the air bubbles contained in the fat phase of the batter causes them to expand rapidly with a pushing and pulling sort of turbulence that opens up the cell structure. Some of the gas phase is lost through the batter, until the temperature reaches the point where the egg proteins and the flour proteins begin to set up. The cake continues to expand and rises in the pan until baking is almost completed, usually in 18 to 20 minutes.

The turbulence is noticeable on the surface of the batter during the first half of the baking period as it moves in from the outside edge of the pan toward the center. It is usually stopped about one-third of the distance to the center, but the cake continues to rise nearly uniformly, with a slightly rounded top higher in the center. Further heat browns the crust and dries out the cake layer to the point where the volume would diminish if left in the oven. Layer cakes usually recede somewhat (contract) in volume when fully baked. The layers can be removed from the pans as soon as they cool enough to handle, and exhibit their lightest and most tender characteristics at that point. The baking rate is most important in obtaining a light and tender layer with a slightly rounded top and desirable crust color. Layers exhibit definite faults, both inside and outside, when baking temperatures are too high or too low.



Courtesy of American Machine and Foundry Co.

FIG. 69. CONTINUOUS MIXER FOR CAKE BATTERS

This continuous cake mixer produces approximately 4000 lbs. of cake batter per hour ready for depositing in pans and baking.

The introduction of special shortenings containing emulsifiers enabled the baker to increase greatly the ratio of sugar and shortening used and by the proper adjustment of the formula balance and layer type cakes can be made as light and tender as desired, to the point where they cannot be handled commercially.

In the larger cake baking plants, use is made of larger batch, vertical cake mixers, and depositing machines to place the proper volume of batter in the pans. Other machines are utilized, such as for automatic icing, cake cutting, and wrapping or boxing.

Foam-Type Cakes

The foam-type cakes have increased rapidly in popularity, particularly angel food cakes, with sponge cakes and chiffon cakes also gaining in sales

volume. The larger commercial cake bakeries tend to concentrate more of their production on small items that package well and are easily handled in the store. The American housewife has not yet given over her cake business to the baker as she has her bread baking, and the potential market for cakes is therefore great when her taste and convenience can be satisfied. A significant share of the market for cakes and other sweet baked products is being captured by the prepared mixes that are now so conveniently available and answer the consumer's desire to "do it yourself."

PIES

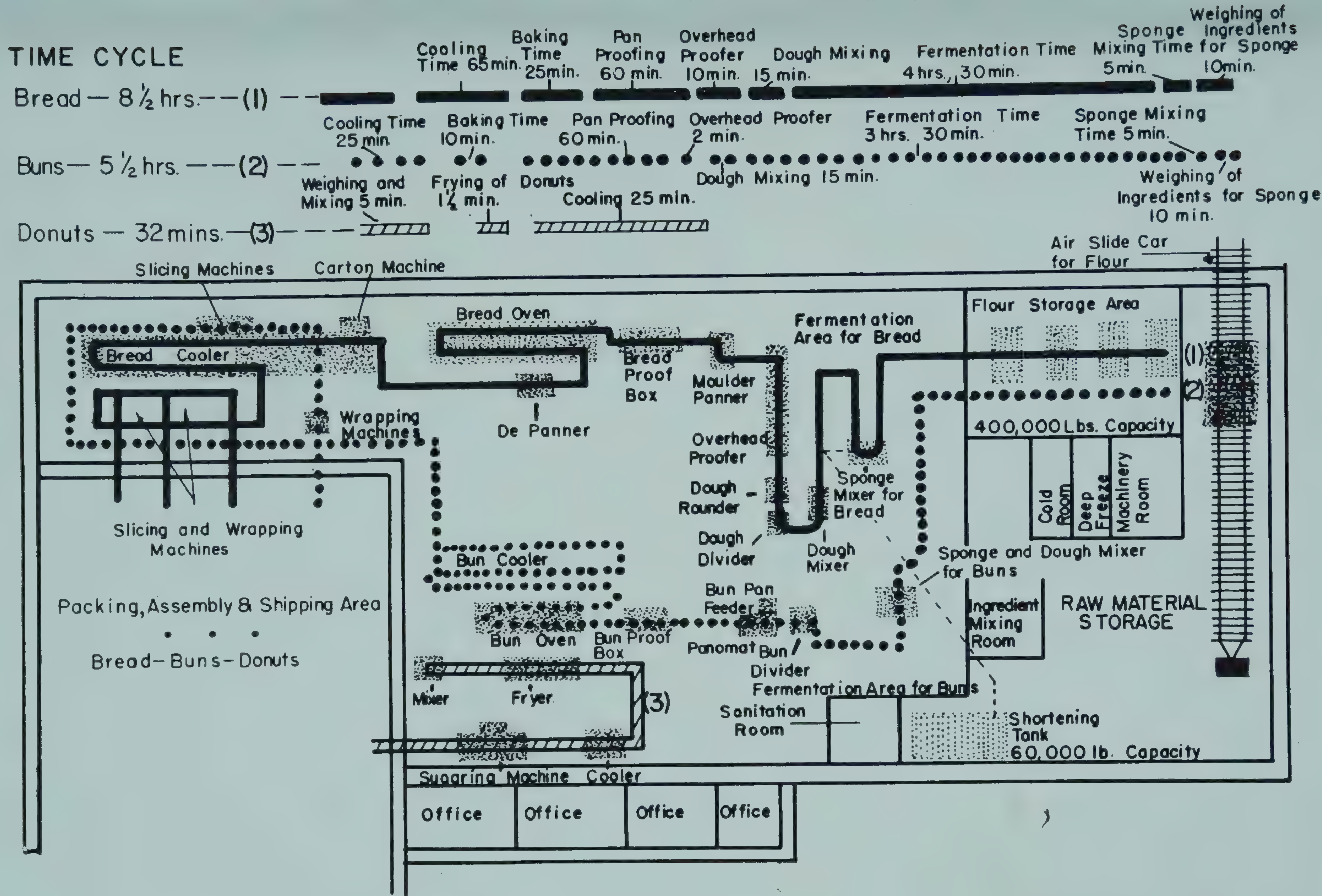
The dough making process for the baking of pies is comparatively simple, since no yeast fermentation or chemical leavening are required. A suitable soft flour of medium low protein content is preferred, unbleached, for pie crusts.

To the flour in a slow speed mixer is added from 50 to 70 per cent of its weight of lard or other non-emulsified shortening and just enough cold (ice) water to partially hydrate the gluten. The shortening mass is mixed, or cut in, with a minimum number of turns to hold the dough together, or until the plastic shortening has been broken down to pieces the size of walnuts. This incompletely mixed mass is then removed and folded over and placed in a cold room at 40° to 50°F. overnight. During that period of time the gluten of the flour "mellows" or softens as it absorbs water with more uniform hydration. The dough is then ready for rolling to crust thickness and placing in the pan ready for the fillings.

The above procedure produces a flaky type of pie crust, as the rolling procedure striates the shortening into layers with the softened flour dough. Should the baker prefer a mealy pie crust, it is only necessary to carry the original mixing nearer to completion and reduce the particles of shortening to the size of peas or smaller.

Many variations of the basic formula and method are used by bakers who specialize in pie manufacture. Sometimes a small amount of sugar is added to give a darker color to the crust and add flavor. Dry milk is sometimes used, and even a little baking powder may be added to some crusts for added lightness. Crust with somewhat different characteristics are preferred for different types of pie fillings.

The wide variety of pies that find favor in different markets can be generally classified as fruit-filled and custard- or cream-filled, which require special preparation of the fillings and baking, or the starch pudding type fillers, and the chiffons, that are added to the baked and cooled pie shells.



Courtesy The Bakers' Digest

FIG. 70. DIAGRAMMATIC FLOOR PLAN AND FLOW SHEET OF A MODERN, NEARLY AUTOMATIC BAKERY

This plant has a capacity of 5000 lbs. of bread, 3000 dozen buns and 600 dozen doughnuts per hour. Time cycle above shows the schedule of time required for each operation for each separate product.

A number of special pie machines are utilized in the larger commercial pie plants to reduce hand labor and speed production.

Freezing of unbaked pies has enabled bakers to produce ahead of demand and hold until they are needed. Frozen pies may be allowed to thaw out and then baked, or placed in the oven directly and baked. Some consumer demand has also been developed for frozen pies sold through the grocers freezing cabinet, either unbaked or baked and frozen. Details of frozen pie production have been described by Tressler and Evers (1957).

The freezer cabinet or walk-in freezing room has given the retail and variety baker an economic advantage because many types of baked products, sweet rolls, coffee cakes, layer or box cakes, and pies may be quick frozen and held for days or weeks until ready for sale. This procedure has greatly reduced the stale loss from oversupply and reduced the long hours of overtime baking preceding special holidays and weekends. Products may be made up in advance during slack days for frozen inventory.

MODERN TRENDS IN BAKING

The modern trend of bringing all control factors at various steps of the baking process into one central panel for observation and control requires at least one person in the plant who knows, and understands the fundamentals of the operation, to maintain successful production. The lack of such experienced, trained technologists has already cost the baking industry millions of dollars in experimentation and product failures.

The next development, that of subjecting every control factor at every step in the baking process to a predetermined set of conditions within an electronic brain type of computer and activator, is currently in process of experimentation (Gemmill 1956). It remains to be seen whether automation can be made so complete that instrumentation will record and correct all the complex and simultaneous conditions from the original ingredients clear through to the finished product. It has been estimated that more than a hundred variables would have to be so controlled in bread manufacture. In spite of the difficulties, the advantages of such a process are obviously so great that success will ultimately be achieved.

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William G. Hoskins

Macaroni Production

Macaroni is a generic term covering a wide variety of products sometimes termed alimentary pastes, which includes the common items of macaroni, spaghetti and egg noodles, plus a whole range of other products of various shapes and sizes obtained by adding special ingredients or by using special forming techniques. Macaroni products are widely known and widely used. In the United States, they are one of the few products made from flour that have enjoyed an increasing per capita consumption. In the year 1937, the per capita consumption was 5.1 lbs. and in 1957, 6.7 lbs. Canada has a record of increasing per capita consumption that is greater percentage-wise than the United States over the same years. Reports from Italy indicate per capita consumption varying from 20 to 60 lbs. per person per year, depending on the part of the country. Consumption of the various macaroni shapes in the United States is approximately as follows: 35 per cent long goods; 35 per cent short cuts such as elbows, shells, etc.; 20 per cent noodles; and 10 per cent specialties such as bow ties, rigatoni, tufoli, and mafalda.

In the United States, the Food and Drug Administration has published a Standard of Identity (Anon. 1953) for macaroni products which establishes ingredients and labelling requirements for the products. These Standards represent practices which are more or less common in other countries of the world as well as in the United States. Ingredients permitted by the Standards are—for the basic raw material—semolina, durum flour, farina, flour, or any combination of two or more of these with water. Permitted optional ingredients are egg white solids from 0.5 per cent to 2.0 per cent of the weight of the finished food, disodium phosphate, onions, celery, garlic, bay leaf, salt or other seasonings. Gum gluten can be added in such quantities that the protein content of the finished food is not more than 13 per cent by weight. Milk macaroni is permitted by the Standards, but rarely made. The same is true of whole wheat macaroni, soy macaroni and vegetable macaroni products which are prepared by the addition of such things as tomatoes and spinach.

Eggs can be added to macaroni products in which case they become either egg macaroni or noodles. Noodles are defined as the product

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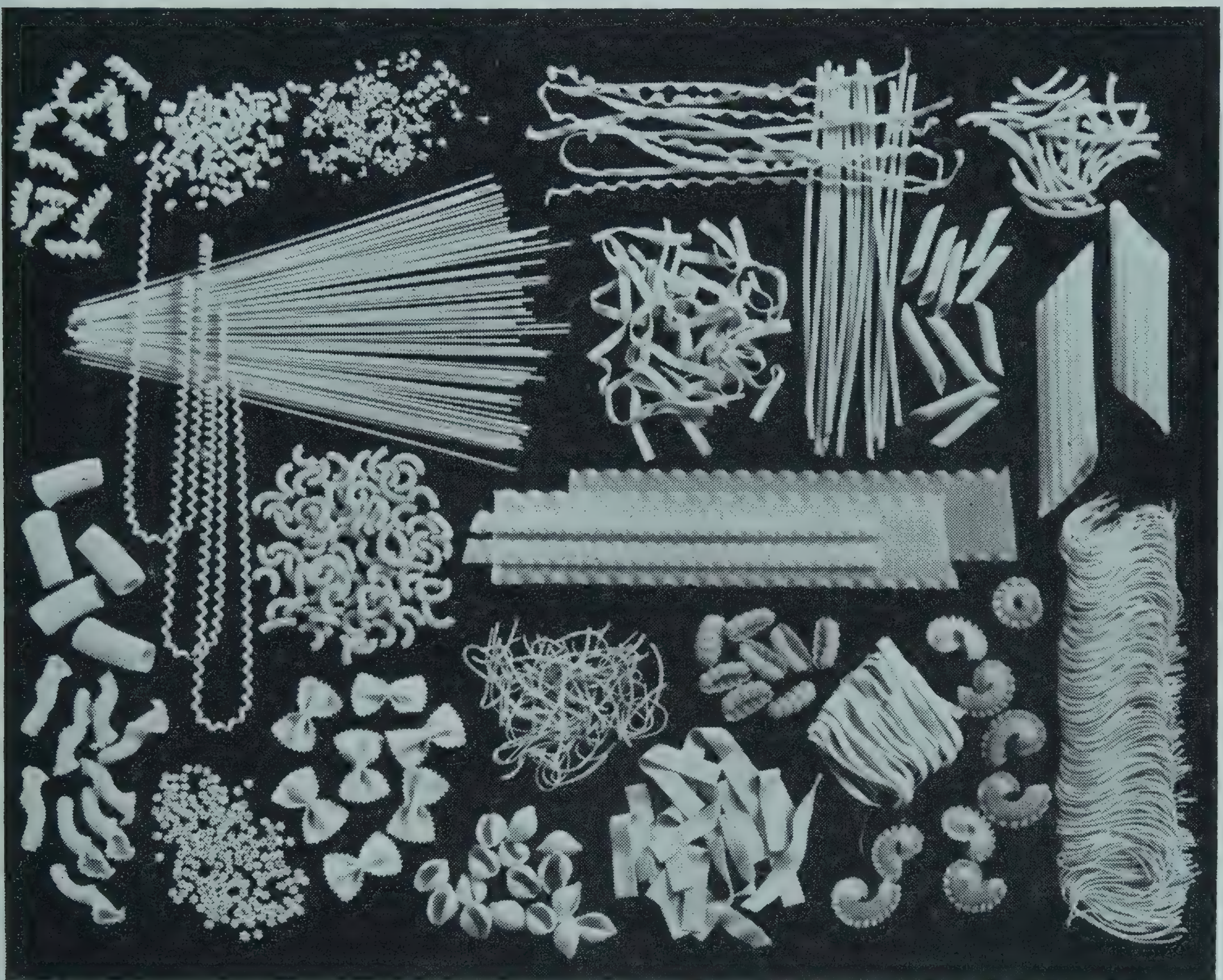
which is formed in ribbon shape and which contains not less than 5.5 per cent by weight of the solids of egg or egg yolk as a percentage of the total solids of the noodle product.

Enriched macaroni and noodles are in widespread use. Enrichment is obtained by adding to each pound not less than 4 mg. and not more than 5 mg. of thiamin, not less than 1.7 mg. and not more than 2.2 mg. of riboflavin, not less than 27 mg. and not more than 34 mg. of niacin or niacin-



Courtesy of Durum Wheat Institute

FIG. 71. TYPICAL MACARONI AND NOODLE SHAPES

amide, and not less than 13 mg. and not more than 16.5 mg. of iron. Enrichment can be put in through synthetic mixtures or yeast. The required amounts of thiamin, riboflavin and niacin are higher than the corresponding requirements for bread flour to compensate for loss in the discarded cooking water. Macaroni products are made in a great variety of shapes. Some manufacturers regularly manufacture more than 70 different shapes which obtain their value from providing variety and interest to meals.

There are so many shapes and sizes that no official standard dimensions are available for most. However, the Standard of Identity makes cer-

Vermicelli — <0.06 — tubular, hollow,
Spray — 0.06–0.11 — cord shaped,
Macar — 0.11–0.27 — cord sha

tain definitions that are of interest. Macaroni, according to the standard, is the macaroni product, the units of which are tube-shaped, hollow, and more than 0.11 inch, but not more than 0.27 inch in diameter. Spaghetti is the macaroni product, the units of which are cord-shaped (not tubular) and more than 0.06 inch, but not more than 0.11 inch in diameter. Vermicelli is the macaroni product, the units of which are cord-shaped (not tubular) are not more than 0.06 inch in diameter.

RAW MATERIALS

The ideal raw material for making macaroni products should lend itself to easy processing on macaroni presses and in driers to yield a smooth and mechanically strong product of uniform color. When the product is cooked in boiling water, it should maintain its shape without falling apart or splitting and should cook to a firm consistency free from a slimy, sticky surface film. The cooking water should be relatively free of starch and the product should be resistant to disintegration due to overcooking. It is generally believed that durum products, and particularly durum semolina, come closest to satisfying these requirements. This opinion is confirmed by the fact that most macaroni manufacturers will use durum when it is available and that the per capita consumption of macaroni decreased in the United States when durum crops were destroyed by stem rust and increased as soon as durum was again available in large quantities. Because macaroni products made from durum have a characteristic yellow color, this color has become associated with good quality and much effort in plant breeding and manufacturing procedure has been directed toward increasing the uniformity and intensity of the yellow color of macaroni.

Durum wheats were originally grown in Russia in a cold, dry climate. They were imported to the United States by Carleton, a U. S. Department of Agriculture scientist who has been called the father of durum breeding and improvement, and for many years the two varieties Kubanka and Mindum were widely used. The varieties Carleton and Stewart were developed from these varieties to resist the prevalent races of stem rust and were in use for many years. However, in 1954 the new race 15B of stem rust, which had begun its depredations in 1950, practically destroyed the durum crop. All-out effort on the development and distribution of rust-resistant varieties, enabled the growers to plant a full crop of durum resistant to the 15B variety of rust in 1957. The new varieties were chiefly Langdon and Ramsey although some Towner and Yuma were also planted. During the period when durum was not available, blends of durum and hard red wheat in percentages from 50 per cent to 100 per cent hard wheat were used to make macaroni.

Until the 15B rust disaster nearly destroyed the durum crop, the American macaroni industry had an ample supply of a very good grade of durum. For this reason the amount of basic research into the properties of durum wheat has been very much less than the amount of research that has gone into the properties of other types of wheat. However, certain things have been determined.

The durum wheat kernel is very hard and both the endosperm and the individual starch kernels are translucent. It is high in carotenoid pigments, particularly xanthophyll and taraxanthin. This hardness and translucency is apparently dependent on the durum being grown in a dry climate such as exists in the Dakotas and in western Minnesota.

In commercially milled wheat flours, the percentage of starch granules damaged mechanically during milling to flour varies directly with the hardness of the grain. In soft wheat, 1 to 2 per cent of the starch granules are damaged; in hard wheat flour, from 3 to 4 per cent, while in durum flour, from 6 to 8 per cent are damaged. The starch of durum wheat is more subject to amylase attack than the starch of common wheats. This may be due to the fact that the durum starch granules are more damaged during milling than is the case with common wheats. The swelling capacity of durum starch is greater than that of hard red spring wheat. The sugar content of durum flours is somewhat higher than that of other wheat flours.

The gluten of durum wheat has different characteristics from that of bread wheat. In the dry state, this results in a very hard endosperm ① which is much harder than the common hard wheats. However, when a dough is made from durum semolina or flour, it is not so tough or elastic ② as dough made from hard wheat. The durum dough will extrude through ③ a small hole at lower pressure than hard wheat dough. When durum is made into bread, the loaf volume is much less than the loaf volume with hard wheat flours. When durum gluten balls are dried in an air oven for testing the per cent gluten in flour, the volume will be much less than the volume of the gluten ball of hard wheat dried in this same oven. Hard wheat flour and farina will make an acceptable macaroni product, but the color is not so yellow as the color of the durum product; the product is not so resistant to overcooking and it apparently does not have so desirable a taste as durum. However, if it is cooked to precisely the correct consistency and served with a good sauce, it is a good food. Further research on the properties of the gluten of durum wheat (as opposed to other wheats) would be desirable.

Durum semolina, durum granular and durum flour are the three general classes of durum products used for making macaroni. Durum semolina is the purified middlings of durum wheat ground so that all of the

product passes a No. 20 U. S. sieve and not more than three per cent passes through a No. 100 U. S. sieve. The durum granular product is a semolina to which flour has been added so that about 7 per cent to 20 per cent passes through the No. 100 sieve. Flour is a product all of which passes through a No. 100 sieve.

Flour makes a dry macaroni which is mechanically very resistant to breakage, smooth and of a clear yellow color. The dry semolina product is not quite so strong mechanically and not quite so uniform in color. It can be identified by the presence of bran specks which are visible to the naked eye. The semolina product takes longer to cook and is more resistant to overcooking than the flour product and causes less cloudiness in the cooking water. Durum granular and blends of semolina and flour have properties intermediate between flour and semolina. Granular and semolina are somewhat more desirable for use in a macaroni plant because they flow from bins into the continuous press more evenly and with less trouble from bridging in bin outlets. The water absorption of flour is greater than that of semolina so that flour products require more drying time than semolina products. There is more slippage in the extrusion screw of continuous presses when flour is used so that production is decreased by the use of flour.

more time
more dry
more resist
bran spec

Effect of Growing Conditions on the Raw Material

Growing conditions to which the crop is subjected can have an important influence on the macaroni-making qualities of the flour made from that wheat. While it is not necessarily true that the amount of protein in a wheat is a direct measure of the quality of the resultant macaroni, still the amount of protein and its quality are vitally important.

Proteins are the principle nitrogen-containing compounds of the wheat kernel, and consequently, of the flour. The primary factor causing the difference in protein content is the difference in environment affecting the nitrogen nutrition of the wheat plant. Any factors of soil, general climate or season which limit the amount of nitrogen available to the plant during the grain formation and maturation period reduce the protein content of the grain. Nitrogen utilized by the plant before heading and blossoming is reflected in total yield. It used to be thought that the wheat plant took up nitrogen early in its growth and that subsequent development depended on this supply. It is now known that the plant is actively functioning and that nitrogen taken up even after vegetative requirements are met is deposited in the grain itself.

The amount and timing of rainfall influences nitrogen available to the plant. If the rainfall is abundant in the early stages of vegetation and inadequate later on, there could be a deficiency in the protein content of

the wheat kernel. Excessive rain at any time could result in leaching of nitrates from the soil. The location of nitrates in the soil is a factor in protein content. The time and quantity of rainfall can remove the accumulated nitrate supply to a point in the soil where it cannot be reached by plant roots.

As was pointed out earlier, it is not necessarily true that macaroni-making quality is directly proportional to the quantity of protein in the flour. If the protein represents a gluten that is desirable, then, of course, higher protein may give a better macaroni product.

Effect of Blight Damage

Blight and related forms of damage can have an influence on the quality of semolina and the macaroni made therefrom. Blight is particularly prevalent in wet, cloudy harvest seasons. Experiments have been performed in which carefully prepared experimental blends containing graduated proportions of light and heavily damaged kernels were milled and the resulting semolina processed into macaroni. It was found that ten per cent of lightly damaged kernels with discoloration evident only at the tip was without detrimental effect, while 25 per cent did not greatly lower the color or increase semolina speckiness. Over 50 per cent by weight would be extremely bad to use in the mill mix. The influence of heavily damaged kernels with visible injury in the crease and other portions of the kernel was more marked. Even five per cent of such grains significantly increased the number of specks in the semolina and decreased macaroni color, while ten per cent was very detrimental.

Sprout Damage

Some experimental work has been done on sprouted wheat to determine the effect on macaroni-making qualities. In one experiment, samples of sound, hard amber durum wheat were sprouted under approximately uniform conditions for varying lengths of time to obtain three distinct stages of sprouting. These three "stages" were defined by length of sprout obtained. Each of the stages was then blended in various proportions by weight with the original sound wheat to obtain mixes for experimental milling.

Sprouting apparently had no effect on the ease of milling, but properties of the dough during macaroni processing were affected. Those made from blends containing a high percentage of badly sprouted wheat were crumbly and "short," but after the customary amount of kneading in batch equipment did have normal consistency. Semolina yield was reduced when more than 20 per cent of sprouted wheat was included in the blend. Diastatic activity of the semolina was greatly influenced by

the proportion of sprouted wheat in the blend and by degree of sprout, while absorption was generally lowered by sprout damage.

Macaroni color was markedly decreased by increased sprouting and there was a highly significant negative relationship between diastatic activity and color. Ten per cent blends of the second and third sprouted stages had more effect on both these properties than 100 per cent of stage one. Five per cent of heavy damage reduced the color score 40 per cent. Semolina from wheat at the first stage of sprouting noticeably affected color at 20 per cent concentration. It appeared from the data secured in the study that the length of the sprout is more important than the amount of sprouted kernels present.

The first large crop of durum grown from the varieties resistant to 15B stem rust was harvested in 1957. Continuous wet weather toward the end of the crop year resulted in large quantities of sprouted wheat. Most of the wheat with a large mixture of sprout in it was made into flour because the yield of this wheat in granular and semolina was too low. This flour made the operation of the continuous mixers very difficult because very slight changes in moisture content would cause the dough to become sticky and form large lumps which would not feed into the extrusion screw properly. Noodles made from the sprouted wheat were so sticky that difficulty was experienced in drying due to the formation of lumps. Because the dough was very sensitive to temperature changes, the extrusion rates in continuous long good spreaders varied considerably across the length of the die, so that the extrusion pattern was uneven. Before the sprouted wheat came into use, a spreader could be made to yield a stick containing no short strands after 10 per cent to 12 per cent trimming. With the sprouted wheat flour, the amount of trim was increased to as much as 35 per cent. These trimmings are returned to the mixer and reprocessed so that the production of the press is seriously reduced by the sprouted wheat. The difficulty may have been caused by the softening of dough due to diastatic activity, which is enhanced by heat, or it may have been due to the general softening of the dough which heating produces even in the absence of diastatic activity. The heating of the dough occurs in the tubes leading to the spreader and is due to friction. The uneven extrusion is probably due to the fact that more friction occurs at the surface of the tube, heating some parts of the dough more than others.

Eggs for Noodles

The only other major raw material besides flour or semolina used in macaroni products is eggs. U. S. Standards of Identity require that anything called noodles or egg spaghetti, egg macaroni, etc., must contain

5.5 per cent of the solids of eggs as a per cent of the total solids in the finished product (Anon. 1953). These egg solids can be put into the product by the addition of frozen yolks, dried yolks, frozen whole eggs, dried whole eggs, or fresh whole eggs or yolks. However, it is the practice in the United States to use dark-colored yolks with an NEPA color score of 4.0 to 5.0 or a carotenoid pigment color of as high as 75 or 80 p.p.m. Frozen yolks are most commonly used for this purpose although a number of manufacturers are using spray-dried yolks.

Between 1945 and 1958 it became increasingly more difficult to obtain an adequate supply of dark-colored yolks. A tendency was noted in the United States for poultry men to grow larger flocks of chickens and to keep them inside buildings on prepared feeds. Part of the reason for this, beside the productivity factor, was that light-colored yolks were preferred for table use, by far the largest market for egg products. Dark color in eggs is obtained when chickens are fed outdoors on natural feed. It appears to be related to the consumption of large amounts of plant pigments. This meant that the dark-colored yolks were available only in the springtime when flocks were normally turned outside, and a diminishing number of farmers were following this practice.

Methods of spray-drying egg yolks have improved greatly in the period since World War II. Both taste and color retention have been good and this has resulted in a more widespread usage of spray-dried yolks for making noodles. One of the advantages of dried yolks is that they can be measured accurately by weight into a dry blender for blending with the correct amount of noodle flour. There is also the advantage of less bulky storage and the elimination of the need for refrigeration.

Whole eggs are infrequently used by the manufacturer of noodle products. Despite the fact that egg whites add something to the strength of the product and its ability to withstand overcooking, the dilution of the natural yolk color by the white solids results in a poorer finished color of the noodle. At times, though, cost considerations encourage the use of whole eggs.

THE PRODUCTION PROCESS

Basically, the production process for macaroni products (without eggs) consists of adding water to flour or semolina in such quantity as to produce a mixture of 31 per cent moisture, mixing these ingredients together for a short period of time, kneading the dough to obtain a plastic, homogeneous mass and then extruding the mass through dies under pressure in such a way that the product comes out in the shapes which are normally seen on store shelves. After extrusion, products are dried, packaged and sold.

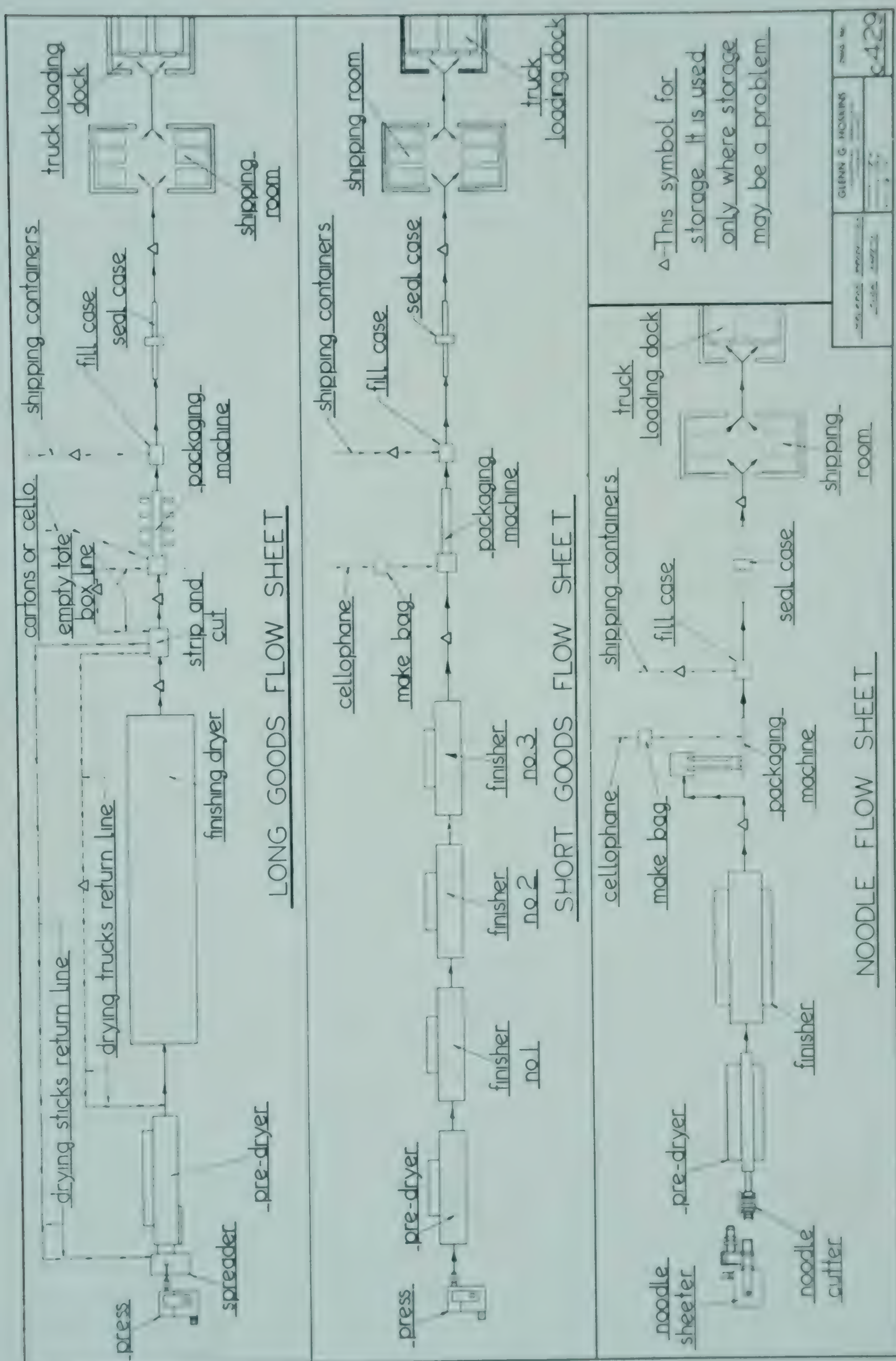


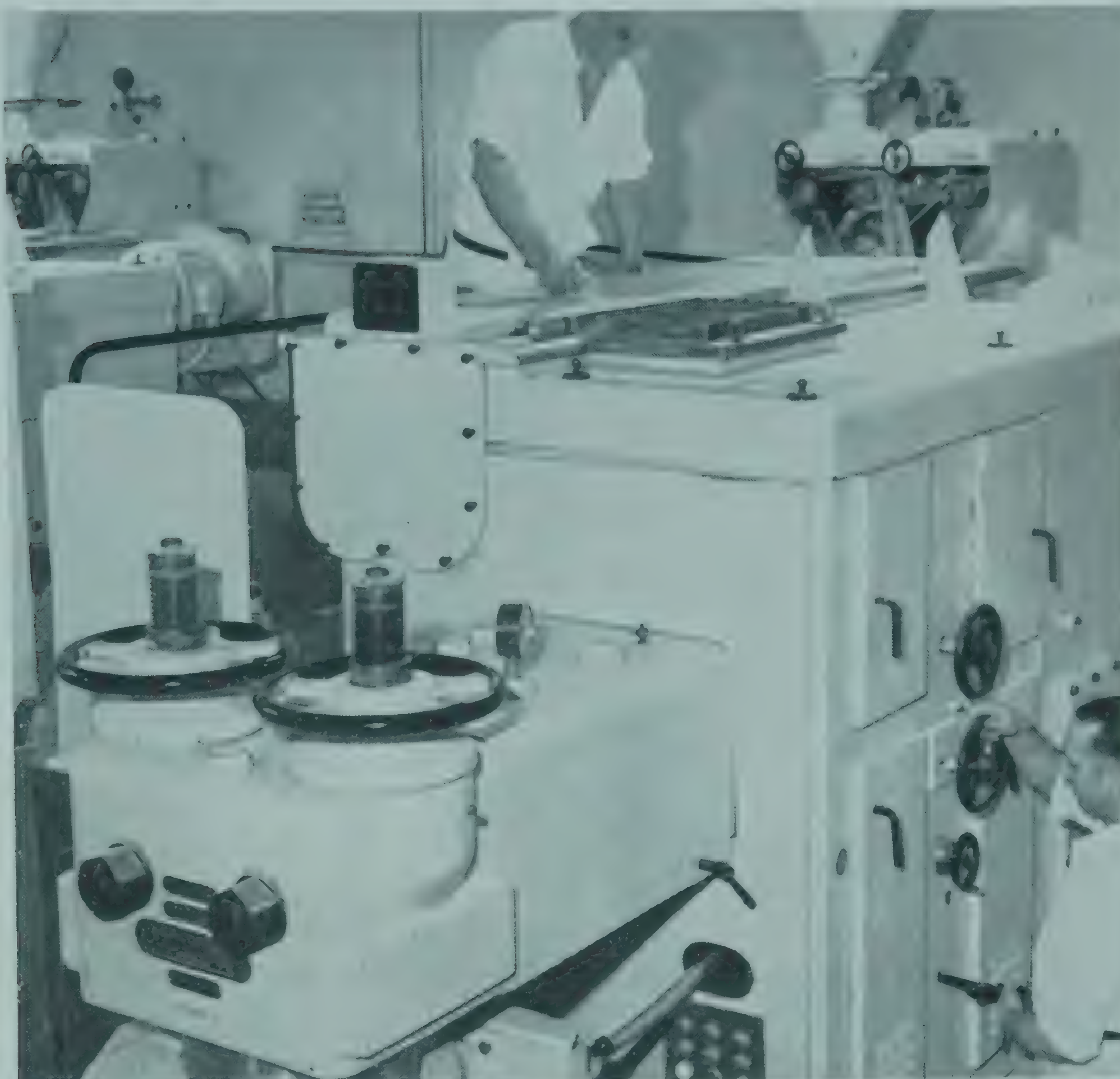
FIG. 72. FLOW SHEET FOR NOODLES AND MACARONI PRODUCTION

Until about 1935 or 1940 most macaroni products were made by a batch process. That is, the semolina and water were weighed and combined in a mixer of about 300 lbs. capacity. The mixer was operated for approximately ten minutes and then dumped into a kneader or gramola. The loose dough was compacted in the kneader, by subjecting it to heavy corrugated rollers which bore down on the dough as it passed under the rollers in a rotating pan. Slabs of plastic dough were cut from the kneader and placed in the chamber of a hydraulic press. Pressure was then brought to bear on the dough to force it through dies at the bottom end of the hydraulic chamber. Pressures of 1500 to 3000 lbs. per sq. in. on the dough were used.

More recently, the functions of mixing, kneading and extruding have been combined in the continuous press. The continuous press is now widely used throughout the world, and only smaller isolated plants still use the batch process. The continuous press is normally equipped with volumetric feeders which provide a continuous flow of semolina and water to the press at rates of 200 to 1500 lbs. of flour per hour. The continuous mixers are equipped with horizontal shafts and blades that move the product slowly forward while mixing the dough. At the end of the mixer, the dough drops into a specially designed auger which is in a tightly sealed cast housing. The auger moves the dough forward and at the same time compacts it, building up pressure and kneading the dough simultaneously (see Fig. 73).

In an auger extruder, flow occurs through a channel of approximately rectangular cross section. Two sides of the rectangle are formed by the leading and trailing surfaces of the auger flight. The bottom of the rectangle is the root of the auger while the top is the inside surface of the barrel or cylinder in which the auger revolves. The auger flights may be visualized as a continuous inclined plane.

The mixed dough which falls into the auger is conveyed forward because of the relative motion between the auger and the cylinder wall when the auger is made to rotate. The rate of forward motion is controlled by the speed of rotation of the auger. This relative motion causes the leading edge of the auger to transmit a forward force to the mixed dough parallel to the direction of the rectangular channel. This conveying force is caused by the viscous drag between the inner surface of the cylinder and the mixed dough. Acting in the opposite direction is the back pressure caused by the die restriction. If the clearance between the edges of the auger flight tips and the cylinder wall surface is small, dough cannot leak back between them; therefore, the forward force which is the greater of the two forces will cause the dough to flow along the helical path of the auger.



Courtesy of Buhler Bros.

FIG. 73. PRESS FOR CONTINUOUS MANUFACTURE OF SHORT-CUT PRODUCTS AT CREAMETTE CO., MINNEAPOLIS

Since the auger is not capable of delivering its full volumetric capacity due to the back pressure induced by the die restrictions, a kneading action occurs. That is, the full volumetric capacity of the auger is greater than the actual amount of extruded dough. Therefore, the flights of the auger in its continuous forward motion must displace the compacted dough in the cylinder, causing a churning action which results in kneading. Due to the friction caused by the flow of the dough in the cylinder, heat is generated. Part of this heat is removed by water-jacketing the cylinder.

On designing an auger for macaroni extrusion, the proper length and pitch must be determined. If the length is not sufficient, the auger will not be able to overcome the resistance pressure of the die, causing the dough to be overkneaded, affecting the quality of the finished product. If the auger is too long, the material will be extruded without sufficient kneading action and again the quality of the finished product will suffer. To increase the efficiency of the auger, its surface is brought to a mirror

polish. The helix angle of the auger flights is varied to allow easier feeding at the inlet and increased pressure at the outlet.

The plastic dough feeds into a chamber or a series of tubes behind a die. The pressure of 1500 to 2000 lbs. per sq. in. built up on the dough by the auger causes the dough to be forced through the die forming it into shapes such as spaghetti, vermicelli, macaroni, shell, rotini and the many other interesting shapes found on store shelves throughout the world.

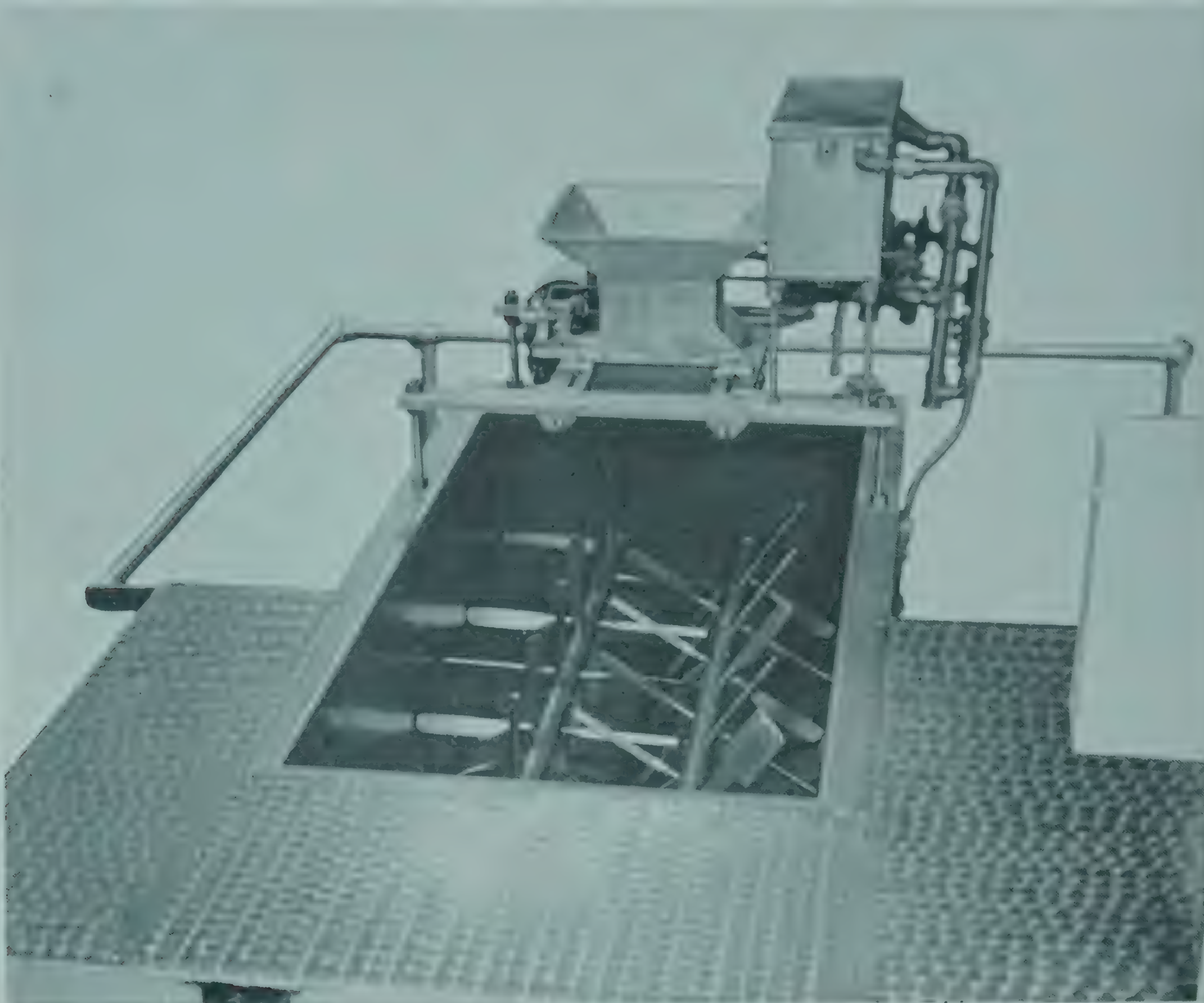
Many manufacturers subject either all or part of the mixer, or the extrusion screw, to a vacuum of 15 to 28 inches of mercury. Such a vacuum makes the extruded product more dense, removes air bubbles from the dough and tends to give the product a more translucent, yellow color.

15-28" Hg
dense
no air bubbles
translucent
yellow

Controlling Feeding and Mixing

The aim in the feeding and mixing functions of the press is to deliver to the auger a continuous flow of dough containing a constant per cent moisture—about 31 per cent on an as is basis. The control of the feed of the flour and water is not a simple matter. One of the factors that enters into this control is the design of the hopper above the press, used to hold a reservoir of flour or semolina for the press. Semolina, being a coarse material, somewhat similar in flowing characteristics to granular sugar, flows rather easily and does not give too much of a problem. Flour, on the other hand, is very much inclined to bridge across an opening and the result is that there are interruptions to flow and occasional flushing. Using flour there is a varying head pressure on the flour feeder which can result in uneven feed.

The design of the hopper over the press is important. Sides of the coned portion of the feed hopper should be as steep as possible. One side should be straight up and down and the others should be sloped at not less than 60° to 70° from the horizontal. Hoppers are normally equipped with vibrators to keep the flour or semolina flowing smoothly. The discharge of the hopper normally is offset from the press feed inlet itself so that the direct pressure of the material does not bear on the feeder. This results in less compacting of the material and a more even rate of feed. The most common type of flour feeder is a simple volumetric device consisting of a short belt conveyor about 6 inches wide by 12 inches long, passing under the feed inlet. An adjustable gate combined with the constant speed of the conveyor belt controls the volume of the flour or semolina being fed into the mixer. In conjunction with the volumetric feeder for flour, the water feed is taken care of by providing a constant head of water in a hopper equipped with a standpipe and a valve to set the rate of water feed.



Courtesy of De Francisci Machine Corp.

FIG. 74. PRESS MIXER SHOWING SEMOLINA FEED INLET AND WATER TANK AT TOP

It can be seen that there are many factors which would prevent the above mechanisms from giving an accurate feed rate. Flour varies in density, for example, because of moisture content and other factors, or because of the amount of material in the hopper above the press. Consequently, the rate of feed changes. The relatively simple valve used for controlling the feed of water can become fouled with sediment or scale and change the rate. In an attempt to correct some of these difficulties, several manufacturers have employed feeders using a gravimetric principle. In these feeders a stream of material is fed onto a small continuous belt. The belt is mounted on a scale so that this scale can sense the amount of material on the belt at any particular time. The weight of material on the belt operates to control the feed gates so that a uniform rate of flow is obtained.

Another method which is used in Europe to some extent uses small scales for both water and flour or semolina. The scales are set for a certain amount of material and come up to weight to be dumped on a timed cycle.

Control of the dough mix is kept within surprisingly close limits. Actual press control is obtained by the operator through the ammeter attached to the auger drive and by regulating the size of dough balls in the mixer. An ammeter connected to the motor power supply is provided. Its function is simple. When the dough gets too dry, resistance to dough flow increases, the press requires more energy and the ammeter reading goes up. The operator corrects the situation by adding more water to the mixer.

Size of dough balls is important. When flour, or semolina, and water are fed into the press, they gradually mix together as they are agitated and worked forward down the mixer. As they mix, the flour particles start to cling together, forming lumps. Size of lumps is dependent on raw material used, type of mixer, amount of water and rate of feed. The press must be controlled in such a way as to get the most possible water in the mix (for color), but not so much that large lumps result and interfere with the product feeding into the auger. Dough balls one-half inch to one inch in diameter seem to be about the right size for most presses.

Egg yolks are combined with water in a mixing tank in the manufacture of noodles. Most often an attempt is made to combine just the correct amount of yolks with water so that the resultant mixture fed to the press will provide both the necessary amount of moisture to make the dough the proper consistency and the correct amount of egg solids to give the correct solids content in the finished product. This results in a rather difficult feeding problem, especially where the flow is regulated by a valve or orifice. The normal practice is to use a constant head tank with a standpipe which discharges through a line having a valve to control the rate of feed. This valve is subject to a buildup of sediment from the egg solids and therefore some noodle manufacturers have substituted a constant displacement piston pump which assures a constant volumetric feed of the egg-water mix.

The egg ingredients in noodles cost nearly as much as the flour, even though they represent only 5.5 per cent of the total solids in the product. Consequently, even a small deviation from the correct rate of feed of eggs can result in a substantial difference in the cost of the finished product. Being on the short side can bring danger of fines or confiscation of the product by regulatory agencies of the Federal government.

Dry blenders, such as the J. H. Day Ribbon Blender, have come into use in the manufacture of noodles and egg macaroni products because it is possible to weigh the dry ingredients into the blenders accurately and obtain the correct final solids content. Where dry blenders are used, there is little objection to the use of a volumetric feeder for the flour-

egg mix since the finished product will contain the correct solids content regardless of the amount of water used for moistening the dough.

Calculation of Rate of Liquid Addition

Flour or semolina normally contain about 86 per cent solids, as used, and the moisture content of the product leaving the press varies 1 or 2 per cent either side of 31 per cent moisture on an as is basis. This means that for every 100 lbs. of flour used it is necessary to add approximately 24.8 lbs. of extra water to get the required dough consistency plus a small amount to replace evaporation while mixing. The addition of egg solids to flour to make noodles requires:

11.12 lbs. of egg yolks at 45 per cent solids
19.25 lbs. of whole eggs at 26 per cent solids
5.27 lbs. of dried yolks at 95 per cent solids, or
5.27 lbs. of dried whole eggs at 85 per cent solids.

Table 57 indicates the pounds of eggs required to obtain 5.5 per cent solids egg content in noodles with a varying egg solids content in the yolks and

TABLE 57

EGGS PER 100 POUNDS FLOUR TO OBTAIN 5.5 PER CENT EGG SOLIDS IN NOODLES

Egg Solid Content	Moisture Content of Flour, Per cent 13	14	14½
Per cent			
43	11.78	11.64	11.57
44	11.51	11.38	11.31
45	11.25	11.12	11.06
46	11.01	10.88	10.82

moisture content in the flour. The normal practice is to mix a 30-lb. tin of frozen egg yolks (45 per cent solids) with 60 to 65 lbs. of water to obtain the correct egg solids content in the finished product. The reason for the variation in the amount of water is that there is a variation in the final moisture of the product as it leaves the press due to the type of press used and the type of flour or semolina used.

Where dried yolks are added to water in the egg dosing operation, an attempt is made to obtain approximately 15 per cent egg yolk solids in the egg-water mixture being fed into the press. In order to get the same mixture as would be obtained with 30 lbs. of frozen yolks added to 60 lbs. of water, it would be necessary to add 14.2 lbs. of dried yolks to 75.8 lbs. of water.

Frozen or dried egg whites are sometimes used to improve the resistance to overcooking in the finished product. One of the principle uses

0.07 – 0.125"

in this connection is for canning where the product is subjected to long periods of blanching and retorting. Standards of Identity permit the addition of 0.5 per cent to 2.0 per cent of the solids of egg whites as a per cent of the weight of the finished food. Table 58 indicates the pounds of water to be added to a 30-lb. can of liquid whites (12.5 per cent solids) fed into a continuous press:

Noodle Production

Noodle production methods differ somewhat from other macaroni products. The problems involved in feeding the eggs required for noodles are described above. The principal difference in manufacturing, however, is that noodles are a flat product lending themselves to production from a sheet of dough.

A few manufacturers extrude noodles through a die in much the same manner in which short cuts are made. The majority, however, employ continuous processing equipment which forms a sheet of dough about 20 inches wide and varying from .070 inch to .125 inch in thickness. This sheet of dough is then fed into a cutter which consists of calibrating rolls which reduce it to the required final thickness, cutting rolls which cut the sheet lengthwise to the required width and cutters which cut the strips of noodle dough to the required length.

TABLE 58

POUNDS WATER TO BE ADDED TO 30-POUND TIN OF EGG WHITES[1]

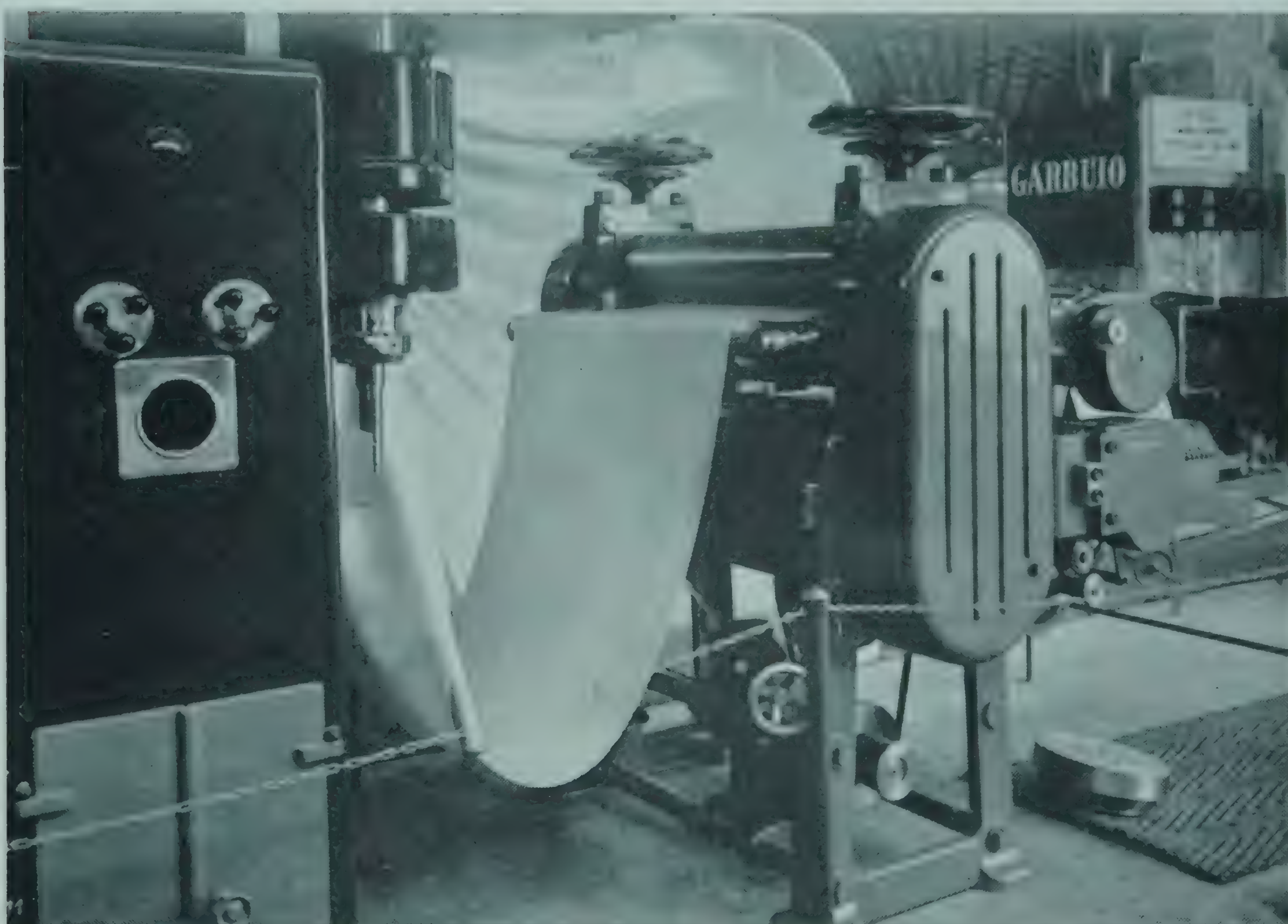
Moisture in Goods Leaving the Press	Egg White Solids in Finished Product (Per cent)			
	0.5	1.0	1.5	2.0
Per cent				
30	152.0	63.2	33.6	18.7
32	181.0	77.5	43.0	25.9

[1] Assumes moisture content of 11 per cent in the finished product.

Basic manufacturing functions with noodles are very much the same as with macaroni in that the ingredients are combined (under the old method) in a mixer for 10 to 15 minute mixing. The mixed products are then dumped into a kneader, or gramola, where the dough is compacted. At the end of this operation, the procedure differs somewhat in that the chunks of dough are fed into a machine called a "dough break." The slabs of dough are fed back and forth through rollers which are moved closer and closer together, gradually reducing the thickness of the dough sheet. When a certain thickness has been reached, the dough is wound on a spindle for later feeding to the cutter.

The first step toward making this operation continuous was a continuous noodle sheeter made by the Clermont Machine Company of Brooklyn, New York. This unit performed the same basic functions as the batch process, but used a continuous mixer which fed dough into a mechanism which extruded a sheet. This relatively thick sheet was folded back and forth on itself, reduced to the required thickness and fed continuously through a noodle cutter.

More recent developments use the standard macaroni press extruding a sheet through a circular or rectangular slotted die, forming a sheet which is fed automatically into a cutter (Fig. 75). The press apparently



Courtesy of Braibanti and Co.

FIG. 75. PRESS FEEDING SHEET OF NOODLE DOUGH DIRECT TO CUTTER

exerts more pressure on the dough than is the case with the old dough break, or the continuous sheeter method, so that the product made on the press has a more translucent, deeper yellow color.

The batch process and the Clermont Sheeter both fold dough sheets in such a way that a large number of small air bubbles are entrapped in the finished product. This causes the product to have a whiter, more opaque appearance than when the product is made on a press, especially under vacuum. Color improvement can be obtained by using Teflon or other plastic liners in the dough slot so that the surface of the dough sheet is very smooth.

Bologna Styles

Many manufacturers, especially those catering to the Italian trade, make what is called "Bologna styles." This classification would include such items as bow ties. Such shapes are formed out of a dough sheet made either continuously or by the batch process and fed into a stamping machine. These machines are somewhat like cookie cutters except that they have attachments to form special shapes and to do such functions as crimping the center of the bow tie.

Twisted Goods

Spaghetti and vermicelli are sometimes sold in "biscuits," twisted clumps, which are dried on trays. These twisted products were formerly formed by cutting a handful of vermicelli or spaghetti in 8 or 10 inch lengths and putting this product in the form of a figure eight on a tray. When the product dried, the "biscuit" held together and was packaged in this attractive form.

Automatic "twist" machines use an arrangement similar to a long goods spreader to extrude the product in clumps of the required number of strands to make the proper sized "biscuits." The clumps of strands are formed into a biscuit after the product has been cut to length. The "biscuits" are deposited on trays for drying.

Vacuum Systems

Fifield *et al.* (1937) developed a method for preparing micro-discs of macaroni dough for studying the color characteristics of durum wheat varieties. These discs were made by pressing a dough of the flour to be tested in a hydraulic press at various pressures and for various times. It was found that the unpressed discs contained many air bubbles which averaged 20 microns in diameter. Upon pressing for four minutes at 3000 lbs. per sq. in., the diameter of the bubbles increased to 800 microns which decreased the number of bubbles in the ratio of 1 to 40,000. At the same time the light transmission through the disc increased sixfold. This illustrated that the depth of yellow color in manufactured macaroni products depended on the number of air bubbles present, and this in turn was a function of the amount of pressure applied and the time for which it was applied.

The vacuum process originally developed by Buhler Brothers in Uzwil, Switzerland, attacked this problem by removing the air bubbles completely by applying vacuum to the mixers or to the extrusion screw. The product produced by this method is slightly more dense than the standard product and has a deeper, more uniform color. It takes slightly longer to cook and the product may stand up slightly better to over-cooking.

Courtesy of Glenn G. Hoskins Co.

FIG. 76. MACARONI DIE WITH REMOVABLE PLUGS

One type of vacuum system is applied by covering the entire mixer with an air-tight cover and exhausting the air by a pump. Where the vacuum is applied on the entire mixer, flour is fed into the mixer through a rotary feeder which makes it possible for the flour (and trimmings) to be introduced into the mixer without allowing air to rush in and spoil the vacuum. The seal at the discharge end of the mixer is provided by the product itself in the auger. Another type of press has secondary mixing chambers with relatively short shafts. The vacuum is applied only to the secondary mixer. The partially mixed dough is transferred from the large to the small mixer through a rotary air lock or a short auger and die with cutoff knife. The vacuum can also be introduced on the extrusion screw chamber. Where this is done, the auger is equipped with an interrupting device which takes the form of a small die part way down the length of the screw. The dough is forced through this die and broken

up into either strands or small chunks. A vacuum is applied on the screw at this point evacuating the air from the product, but arranged so that the product is not removed from the screw. The flighting on the auger then continues and the necessary pressure is built up to extrude the product through the die.

Dies

The manufacture of macaroni and noodle products is essentially an extrusion function. The dough is prepared by the mixer, kneaded in the auger from the mixer to the die chamber and then forced through the die under high pressure. The die performs the function of forming the dough into the characteristic, familiar shapes. Dies are normally made from cartridge brass. However, stainless steel has been used and other materials and alloys are substituted from time to time, as well as a stainless steel frame with brass inserts which can be removed and replaced. Dies are about $1^1/_2$ to $2^1/_2$ inches thick. They are made in both circular and rectangular form, depending on whether they are to be used in presses for producing short goods (circular) or used for an automatic spreader for long goods or noodle sheeting (rectangular).

The simplest extrusion form, of course, is the familiar spaghetti strand. A simple hole is all that is required to form this shape, although the hole through the die is normally tapered from top to bottom. The tubular forms such as macaroni require a pin in the center as described in Fig. 77. Curved pieces are formed by making the thickness of dough different on one side than the other, as is the case with elbow macaroni products. Wavy strands can be produced by having a slightly wider opening on one portion of the slot than on the other so that the thicker portion tends to extrude faster. There is an almost unlimited number of shapes that can be made on presses by varying the size and shapes of holes.

The high pressure required to extrude dough through dies subjects the dies to a substantial amount of wear. The first effect of the wear is to polish the dies smoothly so that after a brief initial period of running the product surface tends to become smoother. One of the problems with stainless steel dies has been that it is difficult to obtain a very smooth surface on the extrusion surfaces, and there has been a tendency toward greater roughness than with brass dies. As production is continued, wear increases to the point where other production problems occur. Many manufacturers keep a set of standards on their product sizes so that the finished products can be checked frequently and dies repaired when product sizes get beyond certain limits of tolerance (Maldari 1956).

Courtesy of Glenn G. Hoskins Co.

FIG. 77. HOW DO YOU PUT THE HOLE IN MACARONI

Left—Only two main parts shape the macaroni. One called the die, is made like a cup with a very thick bottom which has a hole through it of the same size as the outside of the macaroni which it is to make. The other is shaped like a pin with a square head. The long part of the pin is the same size as the hole inside of the finished macaroni.

Center—The pin fits inside of the cup.

Right—Pressure forces the dough around the pin and into the hole in the bottom of the cup. When the dough reaches the round part of the pin, the same pressure forces the dough together and out comes another length of delicious macaroni.

It is often difficult to tell just how die wear will affect production. Under normal circumstances, manufacturers will become conscious of die wear through the warning medium of packaging. Too heavy a product results in less volume per unit weight and there is a resulting slack fill in packages. Gradual wear on solid and tubular products can seldom be detected by visual inspection of the product, but must be determined by actual measurement. Fancy products tend to give some indication of wear by a change in physical appearance. For example, in sea shell production, the flow of dough is at its maximum at the center of the shell, making this point more susceptible to wear than at the ends. As wear increases, the dough flows faster at the center, thereby increasing curvature of the product. Another common warning of wear in shell dies comes in the form of checking either during or after drying. This checking can often be attributed indirectly to die wear and can be eliminated by reducing the thickness of the die outlet.

Wear in the wavy-type products, such as mafalda or wavy lasagne, becomes physically evident by more pronounced or closer curled waves. A cross section of this product should present a flat, noodle type appear-

ance. The wave is the result of greater flow of dough on the ends of the slots in the die, making these ends the points of greatest wear.

Spiral products normally have a cross section like that of a noodle prior to wear. After wear has taken place, the outer circumference portion tends to become larger and rounded, thereby increasing the flow of dough in these points, resulting in a tighter curl or greater degree of twisting.

The problem of splits on short cut tubular products is not always directly traceable to the die, but can generally be blamed on grit that lodges in the die. The grit lodges between the pin and the outlet and prevents proper amalgamation of the dough before it leaves the extrusion opening. Sometimes pins are forced to one side by the grit, thereby increasing or decreasing the rate of curl on an elbow macaroni, or causing excessive curl on long macaroni products.

Die Cleaning and Storing

Many manufacturers have a large number of dies available due to the fact that some 100 shapes may be manufactured in a single plant on perhaps two or three presses. Some dies can make more than one product, but many are suitable for only a single shape. Consequently, the storage conditions under which dies are kept must receive careful consideration.

Cleaning of dies is quite difficult. A relatively dry dough is forced into the holes in the die under pressure of approximately 2000 lbs. per sq. in. A small proportion of the dough remaining in the die at the time of removal from the press is exposed to any cleaning action that might be used. Dough cannot be left in the dies because eventually souring will take place and the resulting acids will attack the brass surface to cause pitting which impairs quality of the finished product.

The normal procedure is to remove dies from the press and place them in a water bath in which the water is continually moving and kept fresh. Dies are often placed on wooden trays and isolated from the walls of the storage tank in order to prevent electrolysis and consequent pitting and corrosion from occurring. Overnight soaking causes the dough inside the dies to become softened and greatly eases the eventual cleaning operation.

Dies are usually cleaned by high pressure water jets in an automatic apparatus which either rotates the dies under stationary jets or moves jets across the surface of a stationary die. Four hours, or more, cleaning time is generally required to remove all traces of dough from inside the surfaces. It is vital that all of the dough be removed or pitting will occur. It is possible to clean dies with high pressure steam jets. However, in the normal, thick die, approximately two inches thick, the high temperature steam tends to cook the dough inside the die and make it very

difficult to remove. High pressure steam can be used to good advantage in cleaning dies which are relatively thin, made of stainless steel with brass inserts. After the dies are cleaned and dried, they are stored in clean neutral mineral oil, or in air, until the next use. Oil storage is preferred.

Special Dies

From 1956 through 1958, considerable experimentation was done on the use of plastic dies. A product called Teflon, developed by DuPont Company, was found to have a very low coefficient of friction and was consequently used as inserts in dies for making noodles and spaghetti. A substantial part of the spaghetti production in Italy was made with Teflon dies in 1958. Other plastic dies were also used with varying degrees of success.

Another development taking place during the 1955 to 1958 period was the use of a rectangular die with a slot for making a sheet of dough for noodles. This slot, when lined with Teflon, produced a sheet having very desirable surface characteristics, yellow and smooth. This sheet was fed through an automatic noodle cutter to produce noodles of very attractive quality.

DRYING METHODS AND MACHINERY

Preparing the Product for Drying

After the products are extruded, they must be prepared for drying. This process consists of arranging the pieces on sticks or screens so that maximum contact of the pieces with the drying air can be attained. In the old batch process, long products such as spaghetti were spread evenly by hand on wooden dowels about $^7/_8$ inch in diameter by 54 inches long. The filled sticks were then placed on racks. Short products were scattered on wire mesh trays or in drawers.

Automatic processing machinery now accomplishes the same results without manual labor. The automatic long goods press has a special network of tubes which spreads the kneaded dough in the compression chamber so that it can be extruded through a long narrow die. This arrangement facilitates the work of the automatic spreader which drapes the strands over the drying sticks. Short goods and noodles are automatically spread on screens in the drier.

Basic Considerations in Drying

Upon extrusion from the press, macaroni is a soft, plastic product containing approximately 31 per cent moisture. This wet product must be

dried to twelve per cent moisture or less to obtain a hard product which will not support the growth of mold, yeast or other spoilage organisms. Too rapid removal of moisture will cause the product to "check." Too slow removal of moisture may permit stretching of long products on the sticks, or souring, or mold growth. To achieve proper drying, the rates of drying must be controlled by adjusting air circulation, temperature and humidity. The drying rate of a macaroni product is determined by the shape of the product, the temperature of the air, the humidity of the air, the moisture content of the macaroni and the velocity of the air.

If a hygroscopic material such as macaroni is placed in a stream of air of given temperature and humidity, it will gain or lose moisture until it reaches a constant per cent moisture which is called the equilibrium moisture. In the case of macaroni, the raw material is a complex, organic system containing starch, protein and other materials which change their properties according to the variety of wheat used, growing conditions, milling procedures, percentage of protein, previous drying conditions and many other factors. Therefore, the equilibrium data obtained by various investigators are not completely consistent. The data obtained by Earle (1948) are as representative as any. These data were obtained by drying the product to constant weight in a laboratory drier with close control of temperature and humidity and adequate air circulation at a temperature of 90°F. The data are summarized in Table 59.

TABLE 59

EQUILIBRIUM MOISTURE OF MACARONI, AND EGG NOODLES AT 90° F

Relative Humidity	Equilibrium Moisture Dry Basis (Macaroni)	Equilibrium Moisture Dry Basis (Egg Noodles)
Per cent	Per cent[1]	Per cent[1]
90	22	..
80	18.2	..
70	16	14
60	13.9	11.9
50	12.1	10
40	10.5	8.5
30	8.8	..
20	7.0	..
10	4.9	..

[1] Per cent bone dry basis.

Drying Rates

On the basis of extensive drying tests run by the authors on spaghetti with a diameter of .069 inches, with an air velocity between 150 and 300 feet per minute and with temperatures varying from 90° to 170°F., drying rates can be calculated by means of the following formula:

$$\log \frac{F_0}{F} = KAt \qquad \text{(Equation 1)}$$

where F = per cent free moisture = $M - M_e$
M = per cent moisture in macaroni (dry basis)
M_e = per cent equilibrium moisture (dry basis)
K = a constant experimentally determined to be .0406
A = square feet of surface area of macaroni per pound of bone dry solids
t = time in hours
F_o = free moisture at zero time
log = logarithm to the base 10

$$A = \frac{.61D}{D^2 - d^2} \qquad \text{(Equation 2)}$$

where A = square feet of surface area per pound of dry solids
D = outside diameter (inches)
d = inside diameter (inches)
$d = O$ for spaghetti and the equation reduces to:

$$A = \frac{.61}{D} \qquad \text{(Equation 2a)}$$

Substituting in equation 1:

$$\log \frac{F_0}{F} = \frac{.0248Dt}{D^2 - d^2} \qquad \text{(Equation 3)}$$

From equation 3, we can derive equation 4:

$$t_a = 12.1 \frac{D^2 - d^2}{D} \qquad \text{(Equation 4)}$$

where t_a = the time in hours required to reduce the free moisture to half its initial value
D = outside diameter of macaroni (inches)
d = inside diameter of macaroni (inches)

EXAMPLE: Plot a drying curve for spaghetti of .072 inch diameter with an initial moisture content of 31 per cent (dry basis) dried in an atmosphere of 90° F. and 80 per cent relative humidity.
SOLUTION: From Table 59 we find that the equilibrium moisture is 18.2 per cent (dry basis) at 80 per cent relative humidity.

$$t_a = 12.1 \times .072 = 0.87 \text{ hours}$$
$$F_o = 31 - 18.2 = 12.8$$

For every 0.87 hours, the free moisture is halved. A calculated drying curve is shown in Table 60.

TABLE 60

CALCULATED DRYING CURVE FOR SPAGHETTI

Time (hrs.)	F = Free Moisture[1]	M = Total Moisture[1]
0	12.8	31.0
0.87	6.4	24.6
1.74	3.2	21.4
2.61	1.6	19.8
3.48	.8	19.0
4.35	.4	18.6
5.22	.2	18.4

[1] Per cent bone dry basis.

DRIERS AND DRYING METHODS

Checking

Macaroni drying is not a simple matter of removing all of the moisture as rapidly as it can be evaporated from the product. "Checking," or cracking of the macaroni piece will result unless the drying conditions are carefully controlled. Checking is caused by the differential expansion and contraction of the layers of macaroni dough under the influence of changes in moisture and temperature. In practice, cracking must be prevented by a relatively gradual removal of the moisture from the product. This is usually accomplished by drying the macaroni in three basic stages.

In the preliminary stage approximately 40 per cent of the total moisture removal is accomplished in 30 to 40 minutes. This case hardens the product and a period of resting or "sweating" in high humidity air allows the moisture to distribute itself fairly evenly throughout the cross section in from one to two hours. From this point, slow drying removes the moisture at a rate which will not cause damage to the product.

Extensive studies of the physical properties of macaroni were carried out by Earle (1948) in order to establish a scientific basis for the understanding of the checking phenomenon. He found that the coefficient of thermal expansion of macaroni dough averaged 58×10^{-6}. The coefficient of expansion related to moisture content is 4×10^{-3}.

Earle compiled a considerable amount of data on the strength of macaroni. The breaking strength under tension varied all the way from 1500 lbs. per sq. in. for noodles which were overdried in the predrier to 7300 lbs. per sq. in. for a commercial macaroni product. He found that harsh preliminary drying decreased the strength of noodles from 3000 to 1500 lbs. per sq. in. He also listed data which showed that macaroni with 14 per cent protein had a breaking strength of 5117 lbs. per sq. in. while a

10.6 per cent protein product had a breaking strength of 3978 lbs. per sq. in.

Calculations based on breaking strength, modulus of elasticity, the coefficient of expansion due to moisture and the thermal coefficient of expansion showed that macaroni containing twelve per cent water on a dry basis and at 90° F. suddenly placed in a current of moving air of 70° F. with a relative humidity such that no change could occur in the surface moisture content would develop a stress of 18.7 lbs. per sq. in. This is a very small value in comparison to the 5000 to 7000 lbs. per sq. in. required to break the macaroni or check it.

Macaroni in equilibrium with air of 65 per cent relative humidity which was moved into 85 per cent relative humidity would develop a maximum stress of 4700 lbs. per sq. in. This would come close to checking the macaroni and would probably actually cause check because of irregularities in the structure. This shows that the checking of macaroni is caused by differences in moisture content and not by differences in temperature. It should be kept in mind, however, that differences in air temperature have a very marked effect on the distribution of moisture so that temperature differences can cause checking indirectly. The physical properties of macaroni are listed below:

Coefficient of thermal expansion (ave.) 58×10^{-6} per °F.
Coefficient of moisture expansion 4×10^{-3} per per cent moisture (dry basis).
Modulus of rupture (breaking strength) at 13 per cent, 5400 lbs. per sq. in. (This varies from 1500 to 7300 lbs. per sq. in. depending on the condition of the product and previous drying history.)
Thermal stress set up by moving from 90° F. to 70° F. air, 18.7 lbs. per sq. in.
Stress set up by moving from 65 per cent relative humidity to 80 per cent relative humidity 4700 lbs. per sq. in.
Specific gravity of spaghetti at 10 per cent moisture content, 1.4.
Modulus of elasticity at 10 per cent moisture dry basis 1×10^{6}.
Modulus of elasticity at 15 per cent moisture content on a dry basis 0.6×10^{6}.

Checking or deformation of macaroni products in the preliminary drier has increased since the vacuum process of extrusion has come into use. If the heat in a long spaghetti preliminary drier is arranged in such a way that the entering goods are dried very rapidly by a blast of hot dry air and then drying is continued at a slower rate to the end of the drying section, the spaghetti will case harden at the beginning. As moisture is slowly removed from the interior, it will contract, but the surface will not be able to follow it as it shrinks. This causes the surface to distort so that the spaghetti looks like rubber tubing flattened by vacuum when it leaves the preliminary drier. The same type of thing occurs with short

cuts, but the product will have ridges from one end to the other, or will shrivel up like a prune.

Normally, overdrying in the preliminary drier will produce white spots or bubbles in the interior of the macaroni. This is caused by the shrinking interior trying to pull away from the case-hardened surface and causing the dough to pull apart at the points where bubbles appear. Usually these preliminary drier "checks" do not cause trouble with respect to cooking qualities.

If dried macaroni is moved into a very humid atmosphere, it will absorb moisture on the surface which will then expand. If this process is carried too far, the surface will pull away from the interior and cause serious checking. Before the vacuum process was adopted, this checking showed up in spaghetti as a crack under the surface which ran at about a 30° angle to the axis of the spaghetti at both ends of the checked place. The shape was very much like a boat. Since the advent of vacuum, this check often shows up in spaghetti as short lines perpendicular to the axis of the spaghetti inside the strand. This is the most serious kind of check.

If a product at 12 or 13 per cent moisture is moved into hot, dry air, the surface will dry and contract. This will cause a very fine network of cracks to appear on the surface. Usually these cracks do not extend very deeply into the macaroni and do not usually cause trouble in cooking. This check is called "tension check" because the surface is in tension when it occurs.

If wet macaroni is dried rapidly, the surface will be dried, but no stresses will be set up because the product is plastic. Under these circumstances, the moisture content at the surface will be small and in the interior it will be large. The solids content at the surface will be large and the solids content in the interior will be small. If drying is continued with this difference in concentration down through the plastic range into the brittle range, there will be no stress set up as long as the drying rate is fast enough to keep the moisture gradient in line with the solids content. When drying is stopped, the moisture will tend to distribute itself evenly. This will cause the surface to expand because it contains too great a concentration of solids and the interior will contract because it contains too low a concentration of solids. This will cause compression check. It is the most common check encountered in macaroni drying. Sometimes it takes several days for this type of check to appear and it may appear after the product has been packaged.

If short-cut macaroni has a small amount of stress trapped in it which is insufficient to cause checking under normal circumstances, it will be more susceptible to checking due to moisture changes than a properly

dried product. If such a product is put into a steel bin when it is warm and this bin is wheeled into an area where the air is cold, the layer of macaroni next to the surface of the bin will be cooled so that moisture will migrate from the hot interior of the bin to the cool product near the surface. The absorption of this moisture by the cool macaroni will cause check. This is quite common. Sometimes under these conditions the macaroni at the sides of the bin will check but the open top surface will not check because the moisture escapes to the air and is not absorbed by the cool macaroni.

In batch macaroni driers, there is often a part of the room which lags behind the rest of the room. Test runs were made on driers where one part of the room was at 15 per cent moisture and there were parts of the room which were still at 21 per cent moisture or more. When the greater part of the room has reached a moisture content of 15 per cent or below, the wet bulb depression throughout the room will often increase rapidly because of schedules set on controls or because of the natural tendencies of uncontrolled driers. This will cause the high moisture part of the drier to lose moisture rapidly and perhaps dry from 21 per cent to 15 per cent in an hour. The product will have a very bad trapped stress-type of check. It is this mechanism that accounts for the fact that a certain spot in the drier will often yield macaroni which is checked and moldy at the same time.

If a strand of spaghetti is supported between two rods approximately six inches apart and a weight is hung on the center of the strand which is slightly lighter than the weight which will break the strand instantly, the strand of spaghetti will gradually bend more and more and after a period of a half hour to an hour it will break. The same mechanism may account for the fact that it takes a long time for some macaroni to check. The continuously applied force due to the weight causes the macaroni to deform slowly in an attempt to relieve the stress. However, there are portions of the dough which will not flow and these portions gradually take on the entire load which was originally supported by all of the dough in the macaroni. Eventually, the rigid "skeleton" which will not flow has insufficient strength to support the stress which has been unloaded onto it and the entire strand of spaghetti breaks.

Where stresses are trapped in the spaghetti, the unevenly distributed water is continually exerting pressure on the surface to expand and the interior to contract. The fraction of the dough which flows gradually accommodates itself to this pressure and the skeleton of the dough eventually cannot support the pressure of the water and checking occurs.

Drying Long Goods

For purposes of drying, macaroni products can be divided into four categories: 1. Long Goods; 2. Short Goods; 3. Scattered Noodles; 4. Twisted and Folded Products. Long macaroni products are most frequently hung on sticks approximately 54 inches long and trimmed to an even length of from 14 inches to 26 inches hanging on each side of the stick. The macaroni is dried on these sticks and then removed from the sticks for cutting and packaging.

At present the most common process for drying long macaroni is the use of a continuous preliminary drier with a sweating section followed by finish drying in rooms. The sticks of macaroni are carried through the preliminary drier on chains. In the first pass through the preliminary drier, the moisture content is reduced from approximately 31 per cent[1] to approximately 24 per cent in 30 to 40 minutes. Air circulation is cut off from the second two passes in which sweating occurs permitting equalization of moisture between the inside and outside of the strands of macaroni. Satisfactory operation of this drier is of great importance to prevent the formation of white spots inside the strand of spaghetti, to prevent stretching of the soft spaghetti and to hold the drying time in the finishing driers to a minimum. Newer preliminary driers accomplish drying on more than one pass. The preliminary drier made by DeFrancisci Machine Corporation, Brooklyn, uses the top two passes for drying and the bottom for sweating and another drier manufactured by Ambrette Macaroni Machine Corporation, Brooklyn, uses the top pass for drying, the second pass for sweating and the third pass for drying. These driers can reduce the moisture to approximately 21 per cent, thus reducing the load on the finishing driers. Secondary driers similar to the preliminary driers have been installed in many factories. These driers reduce the moisture content to 20 per cent or less and reduce drying time in the finishing rooms.

The sticks of macaroni from the preliminary driers are hung on racks containing two or three tiers of sticks on one and three-fourths inch to two inch centers. These racks are moved to drying rooms containing from 12 to 24 trucks. One type of drying room has large fans in the end which pull air through the macaroni on the trucks. Another has smaller fans overhead which can be reversed so that one end of the drier dries while the other rests. The second type is somewhat faster than the first type because the alternate resting and drying at each end permits the use of lower humidity and faster moisture removal during the early stages of drying.

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[1] Moistures are calculated on an "as is" basis unless otherwise noted.

Drying times in uncontrolled driers run as high as five days. More modern driers, utilizing control of temperature and humidity, adequate and efficient air circulation and temperatures as high as 120° F. have reduced drying times to as low as 18 hours for spaghetti and 24 hours for macaroni of medium wall thickness.

Continuous long goods driers are made by Clermont Machine Company, Brooklyn, New York; Buhler Brothers, Uzwil, Switzerland; and Braibanti and Company, Milan, Italy, and others. The Clermont drier consists of a standard continuous preliminary drier with two finishing drier units in series. The sticks are carried through the drier by chains. Each of the two finishing driers is divided into two sections, one above the other with separate controls in each section. Total drying time is between 36 and 24 hours, depending on the size, shape and composition of the product being dried.

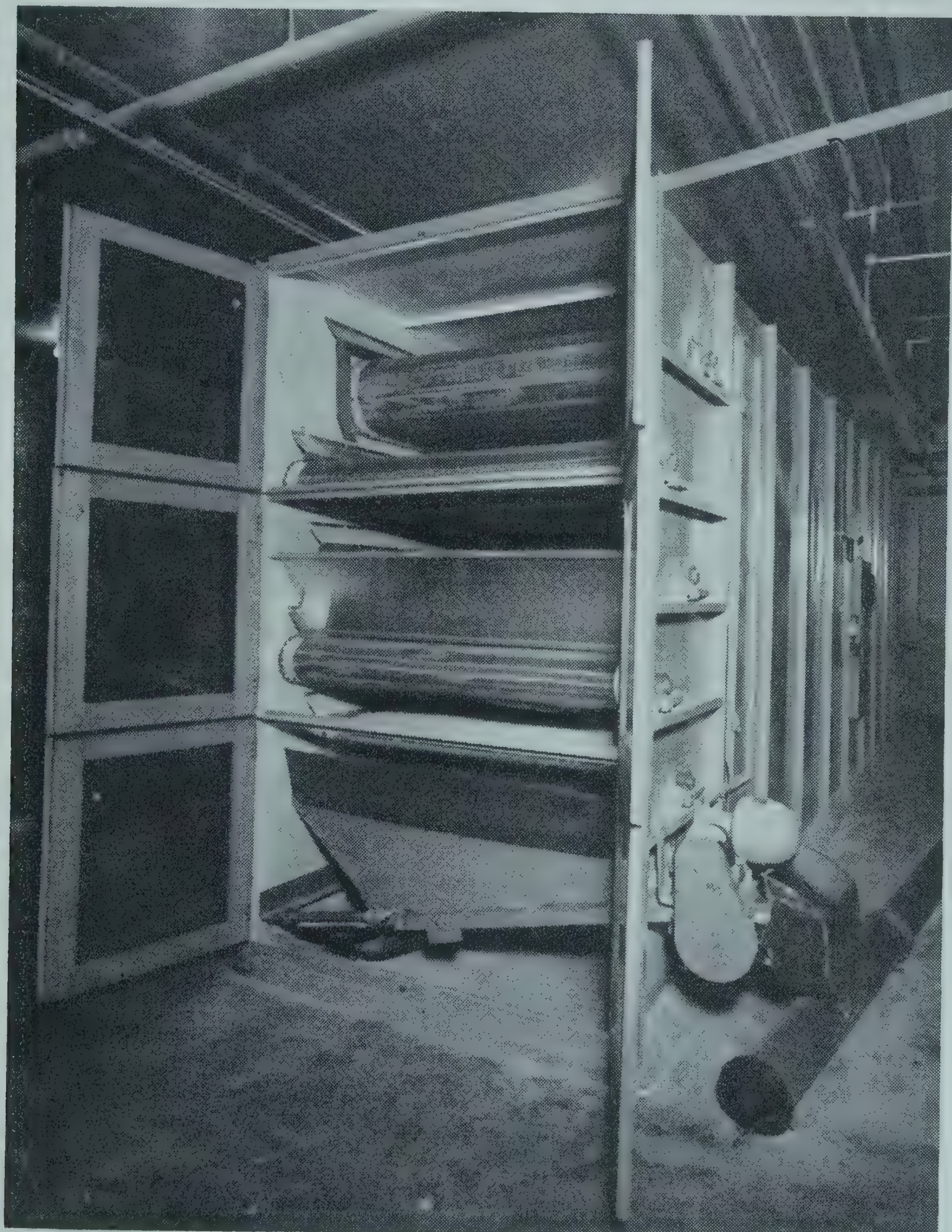
The Buhler continuous drier consists of a preliminary drier and a variable number of identical finish drying units. A unique feature of this drier is that the exhaust air from the preliminary drier is returned by duct to the discharge end of the last finishing drier so that the air is circulated in a completely closed circuit. Moisture is removed from the drier by condensation in the return duct. The Braibanti drier is similar in function. A constant supply of hot water of controlled temperature provides the basis for temperature and humidity control throughout the length of the drier.

Traditionally, drying has been accomplished at temperatures in the range from 80° to 95° F. Experiments, made by the author, have shown that spaghetti with a diameter of .067 inch can be dried at 150° F. in $7\frac{1}{2}$ hours including the preliminary drying, sweating, finish drying and cooling period to yield a product free from check and with a very good color. Macaroni with a wall thickness of .0325 inch was dried in $10\frac{1}{2}$ hours.

If the temperature of wet macaroni products is raised above approximately 170° F., the characteristics of the dough change, probably due to coagulation of the gluten and gelatinization of the starch. The tendency toward checking seems to be markedly reduced so that drying times for long goods can be reduced to three hours or less and in some cases short goods can be dried in less than one-half hour. Infra-red radiation, hot humid air and cooking in boiling water have been used as a means of raising the goods to these temperatures. The product dried with infra-red radiation can be rehydrated by pouring a measured amount of boiling water over it so that all of the water is absorbed in the macaroni and the dried sauce.

Drying of Short Cuts

Short-cut macaroni products can be dried in layers one or two inches deep on trays made by stretching wire or plastic mesh over wooden frames. These trays are placed on trucks with spacers between trays and put in rooms similar to long goods driers where air is circulated through or across the trays. The product can also be dried in drawers with mesh



Glenn G. Hoskins Co.

FIG. 78. CONTINUOUS DRIER FOR SHORT CUT PRODUCTS

bottoms in which the goods are piled from 2 to 4 inches deep. These drawers are placed in a cabinet in tiers 5 to 8 drawers high and air is forced through one half of the drawers from bottom to top and back down through the remaining drawers from top to bottom in a closed circuit by means of circulating fans. These batch driers have been

largely replaced by continuous driers except for large products with thick walls which require a long drying time.

Continuous short cut driers consist of two or more drying cabinets containing several conveying screens which carry the product back and forth over the length of the cabinet as it drops from the top to the bottom screen. A distributor at the feed end of the top screen spreads the macaroni evenly across the width of the screen. Suitable means of air circulation and control of temperature and humidity are provided. Goods are conveyed between units by gravity, pneumatic conveyors or belt conveyors.

A typical drier capable of drying 1200 lbs. of macaroni per hour would consist of a preliminary drier 24 feet long and two finishers each 41 feet long. The preliminary drier would contain four five-foot wide screens supported on a carrier with roller chains at the edges and pipe cross pieces spaced on 6-inch centers. Each of the two finishing driers would contain one resting belt and four drying screens. The resting belt would substitute Neoprene impregnated canvas for the wire mesh. Temperature would be controlled by an instrument regulating steam flow to the heating coils. Humidity would be controlled by a wet bulb instrument regulating dampers or exhaust fans. In some cases, steam humidifiers would be used.

Each make of drier has some unique feature. The Clermont drier blows air across the width of the screens into an air chamber and then returns the air below the bottom screen. Hoskins' driers blow air up through the screens by means of centrifugal blowers to give counter-current flow. The Ambrette drier blows air down through the screens with propeller fans to give concurrent flow. The DeFrancisci Machine Company drier sucks air from both sides of the space between the second and third screens so that air flows up through the bottom two screens and down through the top two screens.

The Buhler drier blows air in at the side of the screens up through the goods and out through the space at the sides of other screens. Reheating coils are placed between the screens and temperature is balanced by regulating the flow of hot water through these coils. Another unique feature of the Buhler drier is that interlocked aluminum slats have been substituted for the mesh screens and the air passes through the space between the slats which are not perforated.

The Braibanti drier has substituted nylon screens with wooden slats for the wire mesh conveyors. This permits the screens to turn over a two-inch roller so that seven or eight drying screens can be put in the space occupied by four or five drying screens in the wire mesh type of driers.

Drum batch and continuous driers have also been used, notably by Buhler and Braibanti. In some installations, a "shaker" is placed at the press. This consists of a series of oscillating screens through which heated air is blown. This apparatus is especially useful where large shapes with thick walls must be dried. The shaker case hardens the product before it enters the conveying system and gives it some additional strength to resist crushing.

Drying of Noodles

Noodles are dried in essentially the same way as short cuts. However, they present some peculiar problems because they are long, sticky and flexible in the wet state and they are more bulky in the dried state than short cuts. While noodles are passing from the noodle cutter to the preliminary drier, great care must be exercised to see that they do not stick together and form lumps. Lumps are caused by noodles piling too deep on conveyor belting, spreading unevenly over the first screen of the preliminary drier, or by cold noodles going into hot, humid air in the preliminary drier where condensation occurs on the noodles. Great care must also be taken not to break the noodles since they are quite delicate when partially dried. Screens must be spaced further apart in noodle driers than in short cut driers to allow for the large volume occupied.

Drying of Twisted and Folded Products

Vermicelli or thin spaghetti is sometimes twisted into "nests" or figure eight patterns. Noodles are sometimes folded and carefully laid on trays to form strips 20 inches long and 2 to 3 inches wide. These products must be dried on trays because the conveying and handling in continuous driers would disturb the pattern of folding or twisting. This drying process is usually carried on in batch driers. However, a continuous drier has been developed by Braibanti in which large nylon trays are pushed back and forth through 52 passes in a continuous drier. The empty trays are automatically returned to the press in a closed circuit.

Controls

Because of the extreme sensitivity of macaroni products to excessive drying rates, the temperature and humidity in macaroni driers must be controlled very closely. A difference in wet bulb depression of 1°F. can mean the difference between a successful drying method and an unsuccessful drying method which causes checked macaroni. Continuous driers lend themselves especially well to control because the driers can be broken down into several units in series and the atmosphere in each unit can be controlled at constant dry bulb and wet bulb temperatures.

Batch driers such as those used for drying long goods present a more difficult problem since the drying must be started with a small wet bulb depression and the wet bulb depression must be gradually increased throughout the drying cycle. This can be done by an operator who manually changes the instrument settings or by a time schedule controller which changes the settings of the wet and dry bulb according to a schedule cut on cams.

Courtesy of Clermont Machine Co.

FIG. 79. AUTOMATIC SPAGHETTI CUTTER FOR REMOVING SPAGHETTI FROM STICKS AND CUTTING TO LENGTH

CUTTING AND HANDLING OF LONG GOODS

One of the more costly aspects of producing macaroni products is encountered in the handling of long spaghetti and macaroni. The continuous production of these items is difficult because it has been necessary to drape the goods over sticks, or dowels, for drying. The development of the automatic spreader in the 1940's simplified these problems a great deal because this device automatically spread the strands out along the stick and cut the goods to length. This had formerly been a hand operation requiring some degree of skill.

Removal of sticks from the strands of dried goods can be accomplished either by hand on a "stripping table" or by a machine which automatically removes the sticks from the strands of goods and cuts the product to the required length.

TABLE 61

COMPOSITION OF MACARONI, NOODLES AND RELATED FOODS

(Based on 100 gm. of edible portion of each food)

Food	Principal Constituents						Vitamins and Minerals								
	Food Energy Cal.	Protein (Gm.)	Carbohydrates Total (Gm.)	Carbohydrates Fiber (Gm.)	Fat (Gm.)	Water (Gm.)	Ash (Gm.)	Calcium (Mg.)	Phosphorus (Mg.)	Iron (Mg.)	Vitamin A (IU)	Thiamin (Mg.)	Riboflavin (Mg.)	Niacin (Mg.)	Ascorbic Acid (Mg.)
Macaroni, (unenriched)															
Dry	377	12.8	76.5	.4	1.4	8.6	.7	22	165	1.5	0	.09	.06	2.0	0
Cooked	149	5.1	30.2	.2	0.6	60.6	3.5	9	65	.6	0	.02	.02	.5	0
Macaroni (enriched)															
Dry	377	12.8	76.5	.4	1.4	8.6	.7	22	165	2.9	0	.88	.37	6.0	0
Cooked	149	5.1	30.2	.2	.6	60.6	3.5	9	65	1.1	0	.17	.10	1.4	0
Macaroni and cheese, baked															
Unenriched	211	8.1	19.7	.1	11.0	58.1	3.1	191	169	.5	450	.03	.16	.4	Trace
Enriched	211	8.1	19.7	.1	11.0	58.1	3.1	191	169	0.7	450	.10	.20	0.9	Trace
Noodles (containing egg)															
Unenriched, dry	381	12.6	73.2	.4	3.4	9.6	1.2	22	199	2.1	200	.20	.11	2.3	0
Unenriched, cooked	67	2.2	12.8	.1	.6	83.8	.6	4	35	.4	30	.03	.02	.4	0
Unenriched, cooked (with 3:1 water absorption)	124	4.1	23.8	.2	1.1	69.9	1.1	7	65	.7	56	.06	.04	.7	0
Enriched, dry	381	12.6	73.2	.4	3.4	9.6	1.2	22	199	2.9	200	.88	.37	6.0	0
Enriched, cooked	67	2.2	12.8	.1	.6	83.8	.6	4	35	.5	30	.14	.06	1.0	0
Rib roast (beef)															
Cooked	319	24.0	0	0	24.0	51.0	1.2	10	185	3.0	0	.06	.18	4.3	0
Hamburger (cooked)	364	22.0	0	0	30.0	47.0	1.1	9	158	2.8	0	.08	.19	4.8	0
White rice															
Raw	362	7.6	79.4	.2	.3	12.3	.4	24	136	.8	0	.07	.03	1.6	0
Cooked	119	2.5	26.2	.1	.1	70.5	.7	8	45	.3	0	.01	.01	.4	0
Precooked, dry	382	8.8	83.3	.4	.2	7.6	.1	4	66	.8	0	.02	.02	.1	0
Potatoes															
Raw	83	2.0	19.1	.4	.1	77.8	1.0	11	56	.7	20	.11	.04	1.2	17
Baked	98	2.4	22.5	.5	.1	73.8	1.2	13	66	.8	20	.11	.05	1.4	17
Boiled, peeled before cooking	83	2.0	19.1	.4	.1	77.8	1.0	11	56	.7	20	.09	.03	1.0	14
French fried	393	5.4	52.0	1.1	19.1	19.6	3.9	30	152	1.9	30	.18	.11	3.3	28
Corn															
Raw	92	3.7	20.5	.8	1.2	73.9	.7	9	120	.5	390	.15	.12	1.7	12
Cooked	85	2.7	20.2	..	.7	75.5	.9	5	52	.6	390	.11	.10	1.4	98
Grits, unenriched, cooked (degermed)	51	1.2	11.0	.1	.1	87.1	.6	1	10	.1	40	.02	.01	.2	0
Grits, enriched, cooked	51	1.2	11.0	.1	.1	87.1	.6	1	10	.3	40	.04	.03	.4	0
Tomato puree, canned	36	1.8	7.2	.4	.5	89.2	1.3	11	37	1.1	1880	.09	.07	1.8	28
Parmesan cheese	393	36.0	2.9	0	26.0	30.0	5.1	1160	823	.4	1060	.02	.73	.2	0
Minimum daily requirements (Adults) (FDA)	3500	65.0	..	..	..	..	..	750	750	10.0	4000	1.0	2.0	16.0	30

COMPOSITION OF MACARONI

Table 61, adapted form U. S. Department of Agriculture Handbook No. 8 (Anon. 1950) compares properties of macaroni and noodle products with other common foods.

In the opinion of the authors, the figures given for cooked noodles are not fairly representative. Apparently the tests were made on canned noodles or something of the kind, because the samples must have gained much more water than normal.

Information released by the National Macaroni Manufacturers Association in 1958 indicates a calorie level for cooked macaroni of 115 to 118 calories per 100 gm., somewhat lower than the figures in Table 61. It should be pointed out that macaroni products continue to absorb water for quite a long time during cooking. Therefore, differences in length of cooking would have an important bearing on the calorie level of a cooked product, as well as on other qualities, such as per cent protein.

MACARONI PRODUCTS QUALITY CONTROL

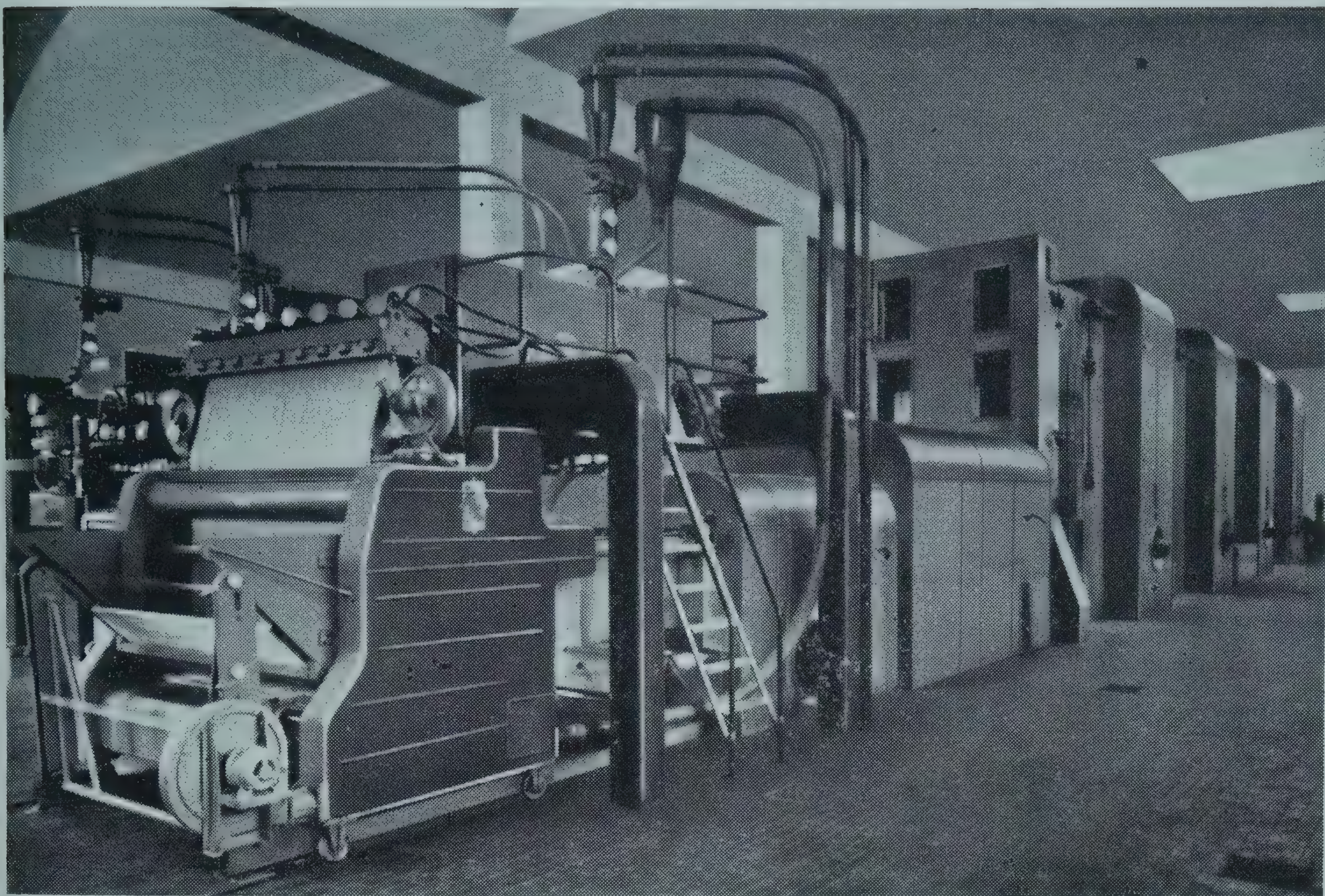
A macaroni-noodle plant quality control program has three purposes:

1. To set up purchasing specifications and see that suppliers comply with them.
2. To analyze production problems which affect both quality and costs.
3. To see that the customer gets a high quality, consistent product.

Following are the basic tests that should be made in a macaroni plant laboratory. It is assumed that the more complex tests requiring extensive training on the part of the laboratory operator, or tests that are required for research and development, would be run outside. Due to the fact that most macaroni manufacturing establishments would classify as small or medium-sized businesses, extent of laboratory facilities and personnel is necessarily limited. The tests to be described could ordinarily be run by an intelligent person with a high school education.

A. Sifting Test.—This test is run to determine the general condition of a carload of flour received at the plant from the standpoint of infestation and weight of materials in bags. The apparatus required for this test is an ordinary production sifter with an 18-mesh screen and a scale. The procedure for this test is to sift a number of entire bags equal to the square root of the number of bags received in the car, note the filth and infestation on the outside and the inside of the bags, and also to note breakage of bags or shifting of load in the car. Bags are weighed to check the percentage of fill. The temperature of the incoming flour is recorded.

B. Granulation Test.—The particle size distribution in a given flour or semolina has an important bearing on the workability and the quality of the product. A premium is paid for semolina which has one-half to one



Courtesy of Braibanti and Co.

FIG. 80. COMPLETELY AUTOMATIC LINE FOR CONTINUOUS PRODUCTION AND DRYING OF LONG SPAGHETTI

Automatic spreader is in foreground.

per cent flour, and anything with more flour should be cheaper. The granulation test is run to check the particle size distribution and see whether the sample conforms to the standards set for semolina.

Apparatus used for making the granulation test is normally the Ro-Tap Sifter. Sieves to be used for testing semolina or granular material would consist of U. S. standard sieves No. 20, No. 40, No. 60, No. 80, and No. 100.

In making the granulation test, samples from the ten sacks of flour taken during the sifting test are thoroughly mixed and a representative 100-gram sample is taken. Starting with a pan on the bottom, the sieves are assembled from No. 100 down to the No. 20 on top. The 100-gram sample is put on the top sieve and the materials are agitated for two minutes. The material left on each screen and in the pan is then weighed.

The Standards of Identity set up by the U. S. Department of Agriculture Food and Drug Administration (Anon. 1953) state that durum flour is prepared from durum wheat and that all of the products should go through a No. 100 mesh sieve. Semolina, on the other hand, will all pass through a 20 mesh sieve, but not more than three per cent through a No. 100 mesh sieve.

Traditionally, semolina has commanded a premium price as the pri-

mary ingredient for making macaroni products. The reason for the premium is that semolina is a product which consists of the middlings of durum wheat. All clears are out of the product and the manufacturer is guaranteed this because of the absence of fine material in the product.

A typical test on a good quality semolina might show the following percentages on the various screens: U. S. No. 20–none; U. S. No. 40–30 per cent; U. S. No. 60–50 per cent; U. S. No. 80–15 per cent; U. S. No. 100–4 per cent; pan–1 per cent. Reliable millers and investigators believe that a semolina handles best in presses and makes better macaroni if a large proportion of particles are in the same size classification. For example, one miller stated specifications of what he thought was nearly an ideal semolina. A test of this "ideal" would show the following particle size distribution: U. S. No. 20–0 per cent; U. S. No. 40–4 per cent; U. S. No. 60–80 per cent; U. S. No. 80–10 per cent; U. S. No. 100–5 per cent; pan–1 per cent.

A product called "granular" in the trade has been in use for a number of years. This is quite similar to semolina except that a higher percentage of flour is left in the product. A typical granulation test for granular might reveal a particle size distribution similar to semolina, but with 7 to 20 per cent of flour in the pan.

C. Ash Test.–The ash test is a partial measure of the quality of the flour. In general, ash content increases as the grade of flour drops. This is not always the case, but is a good indication along with other tests which are recommended. The ash test is frequently used on semolina and granular products as a check to see whether "clears" are being put into the product as flour. This test can be made by running a granulation test and by making an ash test on the portion of the product which passes through 100 mesh.

The apparatus required for this test is a high temperature muffle furnace with accessories. The sample is kept at 1100° F. until it comes to constant weight. (U. S. Department of Agriculture Standards of Identity specify ash on the dry basis, while the mills generally report ash content on the basis of 14 per cent moisture.) Standards of Identity specify that durum flour should have an ash content calculated to a moisture free basis, of not more than 1.5 per cent. Semolina standards specify an ash content of not more than 0.92 per cent, although it is generally agreed that a good semolina should not run more than about .65 per cent ash.

D. Gluten Test.–The quality of the gluten, as well as the quantity, is important to the quality of the macaroni. While this test is not a very accurate test, depending to a great extent on judgment, it does give some idea as to the quality of the gluten in a given flour sample. The procedure for the test is to form a dough ball and wash out the starch under

a stream of tap water. The method is described in the "Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists" (Anon. 1945).

The principal purpose of washing out a gluten ball in a macaroni plant laboratory is to determine the quality of the gluten qualitatively. The color should be noted, particularly as to the amount of grayness, and the strength and extensibility of the gluten should be noted. Gluten suitable for macaroni products should be strong and may be shorter and less resilient than gluten suitable for bread flour.

E. Brabender Farinograph Test.—Irvine and Anderson (1951) have found that macaroni-making quality of semolinas and flours can be predicted by a Farinograph test conducted with the 50-gram mixer and with an absorption equivalent to 31 per cent moisture in the dough. A desirable raw material will rise to a peak fairly rapidly and will break down slowly. A material which has a wide and uneven trace will have a tendency to form a rough product. A raw material which drops off from the peak rapidly will break down in the auger and extrusion tubes of the press and would be expected to give an uneven extrusion pattern on the long goods spreader. Some of the new varieties of wheat resistant to 15B stem rust have this characteristic. It may be that this characteristic was as much responsible for uneven extrusion patterns in the 1957 crop as the diastatic activity caused by heavy rainfall at harvest time.

F. Speck Test.—The speck test is made in order to have a measure of the dirt and bran in a sample of semolina. Apparatus used for this test consists of a 10 × 10 inch square board, with raised edges and a glass plate which fits on top of the edges. The glass plate is ruled in 100 one-inch squares so that the entire surface can be examined by squares.

The box is filled with semolina, leveled off and the glass is placed in position on the product and each square is counted and recorded. A passable grade of semolina would have about 140 bran specks in 100 square inches. A really good grade would test 65.

G. Grit Test.—This test is made to determine the amount of sand or sediment in a sample of semolina or flour. Sand can lodge in the die and cause splits and streaks in the product, particularly in thin-walled macaroni. A measure of the sand and other insoluble sediments is also a partial measure of the sanitary condition of the sample.

Apparatus required for the test consists of a 500 ml. wide-mouth separatory funnel fitted with a glass stopcock, evaporating dish and some carbon tetrachloride. A 100-gm. sample is measured into the separatory funnel and 400 ml. of carbon tetrachloride is added and stirred. The grit will settle to the bottom of the funnel and is drawn off into an evaporating dish. Carbon tetrachloride is poured off (without disturbing sediment)

and the sample is washed once with a small amount of carbon tetrachloride which is again poured off. When the remainder of the carbon tetrachloride has evaporated, the grit is weighed to four decimal places.

II. Moisture Test.—Moisture tests are extremely important throughout the manufacture of macaroni products, including testing the incoming raw materials. As far as semolina and flour are concerned, a manufacturer is paying for a product containing 14 per cent moisture. If the product actually contains 15 or 16 per cent, he is getting one or two per cent less flour than he pays for, the difference being made up in water. The same principle holds true in shipping macaroni products out of the plant. The macaroni industry is highly competitive and a one per cent difference in moisture content can make an important difference in net profit.

Moisture testing is also important in determining effectiveness of drying and effectiveness of control of drying in the various stages. Standard atmospheric and vacuum oven tests for moisture in macaroni products are specified by the Association of Official Agricultural Chemists. Fast and reasonably accurate tests can be obtained with resistance-type moisture meters. A moisture meter which compresses an unground, weighed sample to a predetermined volume is reasonably accurate from approximately 7 to 17 per cent. Resistance moisture testers which apply a fixed pressure and measure the electrical resistance between the piston and the bottom of the compression cylinder are quite accurate for moisture from about 8 to 17 per cent when the samples are ground. The accuracy drops off somewhat above 17 per cent because the thickness of the sample becomes more important in this range where the resistance is fairly low. Accurate tests from about 8 to 25 per cent can be made with testers in which the sample is compressed to a predetermined pressure and the resistance is measured from one concentric ring electrode to another in the base of the compression chamber.

The Standards of Identity specify that durum flour and semolina contain not more than 15 per cent moisture. Actually, millers normally ship flour at 14 per cent. Macaroni products, according to the Standards of Identity, shall contain not more than 13 per cent moisture. Good practice, to prevent deterioration of quality and checking, dictate that this final moisture content of long goods should generally be around 10 per cent and on short goods about 11 per cent, since these are the moisture levels the products will probably reach on store shelves.

In normal plant operation, moisture tests should be made on incoming semolina or flour, on the final moisture content from continuous driers, moisture content in batch driers and on samples of each product, each day taken from finished packages from the packing room.

I. Grading Finished Goods.—This test is run in order to establish a standard of comparison of finished goods. It is important for finished goods to be consistent from day to day so that a retail customer can be assured of buying products with consistent cooking time. For example, if strand thicknesses or wall thicknesses are allowed to become excessive through die wear, cooking times will change from the time stated on the packages.

Besides checking the finished dimensions of the product frequently, classifications should be made on the basis of a comparative weight on an established sample of pieces sorted as follows:

1. Perfect pieces
2. Deformed, flattened or bent
3. Specks
4. Streaks
5. Splits
6. Checks
7. Dirty
8. Broken

J. Cooking Tests.—The cooking test is probably the most important test run on macaroni products. No test has become standard, but three types are of interest.

The most commonly used test consists in cooking the product and testing portions of it at one minute intervals by eating a few strands to determine the consistency. The product is then overcooked for as much as a total of 30 minutes to determine whether it will cook to pieces. The following classification of qualities when marked in order will give a numerical value to the quality of the cooked product and aids in making the test somewhat more objective.

Appearance, form

Uniform, no deformation of pieces	(4)
Slight deformation of pieces	(3)
Uneven shape, some split pieces	(2)
Collapsed and/or badly split	(1)

Color

Amber or creamy white, no specks	(4)
Creamy white, slight specks	(3)
Pale white or specky	(2)
Grayish or very specky	(1)

Flavor

Bland wheaty flavor	(4)
Bland	(3)
Starchy, lacks wheat flavor	(2)
Off-flavor, e.g. stale, musty, etc.	(1)

Tenderness (when cooked through)

Firm, slightly chewy	(5)
Tender, not chewy	(4)
Soft	(3)

Tough	(2)
Very tough	(1)
Stickiness (adherence of product to itself)	
No adhesion	(3)
Slight stickiness	(2)
Pronounced stickiness	(1)
Total Score (Maximum: 20 Points)	—

The Italian professor Berazzio (as quoted by Hummel 1950) developed a more objective cooking test which is widely used in Europe and for which equipment is made by Buhler Brothers, Uzwil, Switzerland. Samples of 250 grams of dried products are cooked in one liter of one per cent salt solution in each of two cooking vessels, heated in a constant temperature oil bath at 218° F. This causes the product to cook at a temperature of 208° F. so that disintegration of the product caused by the turbulence of boiling is kept to a minimum. The cooking time in one vessel is 18 minutes and the cooking time in the other vessel is 28 minutes. After the macaroni products have been cooked, the samples are drained for five minutes and then weighed. The difference in weight between the cooked sample and the dry sample gives the water absorption during cooking. The volumes of the dry sample and the cooked sample are measured by water displacement and the increase in volume recorded. The water in which the samples have been cooked is placed in a graduated glass tube and the suspension of starch and other materials is allowed to settle for half an hour. The height of the milky portion which settles out at the bottom is measured. In some cases, a portion of the cooking water is evaporated to dryness to measure the amount of solids dissolved in the water. It is stated that less than six per cent dissolved in the cooking water is very good and that eight per cent is about average.

Radley (1954) describes an interesting cooking test which might have wide application in research work. Approximately three grams of the product to be tested are placed in a wire basket with a lid. This is weighed in cold water at 68° F. and is then plunged into rapidly boiling water. At a given time the product is removed from the boiling water and re-weighed in cold water. It is then slung to remove the moisture and the outside of the basket is wiped dry. The basket is weighed in air. Then the product is returned to the boiling water. This is repeated until the product has completely disintegrated and the basket is then weighed in water, empty. The curve plotted from the weight values determined in air indicate the rate of absorption of water. The curve obtained from plotting the values obtained by weighing in water shows the rate at which the product is disintegrating since the water in the macaroni

does not contribute to the observed weight when the product is submerged.

K. Egg Solids.—This test is made to see whether the actual solids content of the yolk, whole egg, dried egg or egg white meets the guarantee furnished by the supplier. This test is made with an air oven and an analytical balance and is performed by measuring the weight loss of a sample placed in an air oven for 16 hours at 212° to 217°F.

Frozen dark-colored egg yolks will normally contain about 45 per cent solids. Frozen whole eggs contain about 26 per cent solids. Dried yolks and dried whole eggs and dried whites all contain approximately 95 per cent solids. Frozen egg whites normally contain about $12^1/_2$ per cent solids.

L. Color.—Color of macaroni made from a given raw material can be predicted by:

1. Determination of pigment content and lipoxidase activity.
2. The manufacture of a disc of macaroni dough which is evaluated by:
   a. A reflecting photometer (Matz and Larsen 1954).
   b. Visual comparison with whirling paper discs, consisting of white, black, yellow and red.
   c. Visual comparison with other samples.
3. The manufacture of a noodle about 50 mm. wide and comparing its color with the whirling disc.
4. The manufacture of macaroni on small laboratory equipment.

Method 1 was worked out by Irvine (1955) of the Grain Research Laboratory of the Board of Grain Commissioners in Canada. It is based upon the fact that lipoxidase activity destroys the pigment in semolina during mixing. This is the fastest method, requiring only 30 minutes to obtain results. The pigment is determined by extraction with *n*-butyl alcohol solution and measurement of light transmittance at selected wave lengths.

Lipoxidase activity is measured by Warburg techniques. The predicted macaroni color score is obtained by substituting the top values of light transmittancy and lipoxidase activity into an equation which can be found in the original reference. Extensive research shows good correlation between predicted and natural color scores.

Method 2 uses macaroni discs formed by mixing, kneading, sheeting, pressing and drying a small quantity of semolina to form a disc approximately 50 mm. in diameter and approximately three mm. thick. This is an accurate method, but drying of the discs takes as much as two days.

Method 3 using a rolled noodle in place of the disc is faster because the porous noodle dries faster than a disc without checking, but the opacity caused by air bubbles obscures the yellow color somewhat.

Method 1 is recommended because it is simple and fast. However, it does not predict the amount of grayness in the macaroni. This can be determined by studying the color of the gluten washed out of the semolina.

CANNED AND FROZEN PRODUCTS

Quite a large volume of spaghetti and other products is used in the United States in canned form with meat balls, tomato sauce or other types of sauce. The flow sheet of spaghetti canning procedure would include the operations of blanching, cooling, filling, saucing, closing, processing, cooling and storage. Details of the procedure used will vary quite widely from one manufacturer to another. However, certain considerations are uniform and are worthy of mention.

Blanching (or preliminary cooking) is done in a great deal of water at boiling temperature. Spaghetti is added in relatively small amounts to prevent matting of the material when it starts to swell and absorb water. Some manufacturers use undried spaghetti only a few minutes off the press. A continuous overflow of water during the blanching is arranged to eliminate the accumulation of excess starch. If the product is not blanched sufficiently, there may be excessive matting of the final product. Overblanching may result in loss of texture, poor sauce absorption or adhesion and dilution of sauce flavor. A blanch which is just long enough to soften the strands throughout and still prevent matting of the canned product should be employed. This will be approximately 7 to 10 minutes in boiling water. Under these conditions, weight of water somewhat greater than the weight of dry spaghetti will be absorbed.

After blanching, spaghetti should be cooled with cold water to stop the cooking or softening action. A gradual cooling over a period of one to one and one-half minutes under cold water sprays is supposed to be better than instantaneous cooling.

In most cases, spaghetti is filled in cans by hand since its nature precludes automatic filling. The weight used depends on the make-up of the sauce, the size of the can and the amount of water that has been absorbed during the blanch. The amount of fill must be determined experimentally.

Experience has shown that the rate of heat penetration is increased when containers of spaghetti, which tends to mat in the bottom of the can, is processed on the side. Process times used for spaghetti having a pH below 4.8 are given in Table 62 on page 319. Canning process times for any product should only be established after careful study of the product, can size, etc. by competent technical personnel. Cans should be cooled promptly in a water bath to an average temperature of 100° F. following the processing.

It can be seen from the above description of the spaghetti canning

TABLE 62

SPAGHETTI CAN PROCESSING TIMES

Can Size	Initial Temp. °F.	Process Time at 240 °F. Min.	Process Time at 250 °F. Min.
300 × 407	140	55	50
303 × 406	140	60	50
307 × 409	140	70	60

process that the product is exposed to a period of long cooking. If the product is not made out of the highest quality raw material, it will become soft and mushy. Some manufacturers of canned products add materials to the basic product of durum wheat semolina to prevent this breakdown. One such product is egg whites in quantities from about 0.75 per cent to as high as two per cent. Egg white causes the product to retain its structure and firmness in spite of the excessive cooking.

Another product that can be added is gum gluten. According to the Federal Standards of Identity, gum gluten can be added in an amount sufficient to bring the total protein content of the finished product up to 13 per cent. Gum gluten is effective in increasing the resistance to overcooking. However, some additional grayness is added by an excessive quantity of gum gluten. Ordinarily, an amount necessary to bring the final protein up to 13 per cent will not be undesirable and will help considerably in strengthening the product.

Many macaroni and noodle products are being used in precooked frozen dinners of macaroni and cheese, macaroni and spaghetti and meat sauce, tuna and noodles and many others. Somewhat the same preparation techniques are used for freezing as are used for canning. Gum gluten, egg whites, and additional protein added by soy flour all have an influence in making the product stand up during processing and reheating. It has been established experimentally that a precooked frozen product reinforced with gum gluten and cooked slightly less than would be desirable for immediate consumption, can result in a finished product that is very near in palatability and firmness to a fresh cooked product. Complete details of freezing techniques and recipes for macaroni products have been compiled by Tressler and Evers (1957).

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C. G. Harrel

Manufacture of Prepared Mixes

INTRODUCTION

Patent protection on prepared mixes is far more difficult to secure than patent protection on mechanical or chemical developments. Probably one reason why this is true is the fact that, over hundreds of years, many different recipes and formulas have been developed in the home, hotels, and institutions all over the world. These formulas and recipes have been widely published by various magazines, newspapers and other agencies. Because of the difficulty of obtaining patent protection, secrecy is frequently resorted to in an attempt to guard any new developments in the prepared mix field. Under the revealing eyes of modern analytical chemistry or through leaks which frequently occur, the lifetime of such concealment is often very short. Even so, a lead of six to twelve months on a new product is sufficient in many instances to obtain a major portion of the market existing for such a product. Many who read this must have a sympathetic understanding when certain modern developments are not mentioned, because it may be your industrial organization or mine that is protecting itself. Such information will be revealed when it becomes antiquated or replaced by better ingredients, methods, or processes.

The first prepared mix was made in 1849 when Henry Jones of England assigned a United States Patent Number 6418, to J. Fowler of Baltimore, in which a balanced self-rising flour was prepared from an aged mixture of flour and tartaric acid blended with sodium bicarbonate. Truly self-rising flour is the grandfather of all prepared mixes.

Pancake or griddle mix next appeared on the horizon. This mix consists of various combinations of wheat, corn, buckwheat and rye flours with the proper leavening ingredients, and sold nationally with the Aunt Jemima brand dating back to the 1880's. This mix was first advertised in magazines not long after 1880. The brand was acquired by the Quaker Oats Company in 1925. After these early developments there followed doughnut mixes, cake mixes, biscuit mixes, etc.

Prepared mixes are distributed in four distinctly different channels:

1. Through grocery stores for home consumption. The majority of

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such mixes call for the addition of eggs and some for the addition of both eggs and milk.

2. Through institutions such as restaurants, hotels, hospitals, orphanages, etc. This type of mix usually is a complete mix requiring the addition of water only.
3. Through bakeries. These are very similar to the institutional mixes but are usually put into much larger-sized packages. A great number of them are complete, but they are also marketed as incomplete mixes, calling for the addition of one or two ingredients.
4. Mixes for the Armed Forces. These are complete mixes. Such mixes must have a greater stability than any of the other ones mentioned above. To achieve this it is necessary to produce these mixes from a low moisture flour in the proximity of 5 to 7 per cent as shown by research investigation at the Quartermaster Food and Container Institute for the Armed Forces (Matz *et al.* 1955).

There are five different types of mixes, namely:

1. Those leavened by chemicals for use in making doughnuts, cakes, muffins, etc.
2. Those leavened by yeast, examples of which are those used for making bread, rolls, buns, yeast raised doughnuts, etc.
3. Those leavened by aeration with or without the addition of chemicals acting as leavening agents; examples of which are foam type angel food, sponge cake mixes, etc.
4. Those leavened with chemicals and flavored with fermentation products from yeast such as instant bread mix, developed by the Quartermaster Food and Container Institute (Davis and Matz 1958, Miller *et al.* 1958).
5. Non-leavened, such as pie crust mix.

Prepared mixes bring to the user the following benefits: (A) convenience; (B) uniformity of product; (C) better products; and (D) more economical products.

They bring convenience in that there is no weighing or measuring of individual ingredients. Measurements, particularly in the home and some institutions, are exceedingly inaccurate. Measurements and weighing of ingredients consume time and frequent losses of individual ingredients occur, all of which result in products which are not uniform from day to day or week to week. Failures in products baked from premixes seldom occur, which is a point of economic importance.

Prepared mixes bring to consumers, particularly to the housewives and smaller institutions, better products because the uniformity of such prepared mixes are checked hourly to determine that the right amount of

individual ingredients are present, that they are homogenous and conform to existing rigid standards, particularly in performance.

Mixes bring the consumer ingredients of improved quality, which are not available to many of the consumers, since the user does not have access to the improved leavening ingredients, the more powerful emulsifiers, specially developed milk solids, etc.

Prepared mixes employ highly developed methods of bulk handling of ingredients and bring about certain savings that are passed on to the consumer. Bulk handling of shortening saves approximately $1.80 to $1.85; flour, 20¢ to 40¢; sugar, 25¢ to 40¢; cornstarch, 25¢ to 40¢; corn flour, 20¢ to 40¢, per cwt. This economy cannot be secured by housewives, small institutions and bakeries, due to additional cost of packaging, labor, etc. These savings, together with modern methods of manufacturing, have literally brought the automobile assembly line into operation in the mix industry and made a firm foundation for the existence of prepared mixes for all time.

Examining the growth of prepared mixes, Anderson of General Mills, Inc., in a talk before the 1954 meeting of the Grocery Manufacturers of America, said:

> "Probably no single food product group can match the growth of baking mixes since 1948. What is more significant is the fact that this growth has largely resulted in entirely new business. When you stop to consider that today there are some 600 million cakes baked with cake mixes each year, and that during this same time the cake flour business has given up only a volume equal to 150 million cakes, it is plain to see that approximately three-fourths of industry volume is new business."

Ten years ago there were some two feet of shelf space in modern super market allowed for the display of prepared mixes. Today mixes occupy approximately 20 to 25 feet of shelf space. Nationally prepared mixes are fundamentally new, and their growth has been phenomenal.

It is estimated that the sale of family mixes at present amounts annually to $300,000,000, bakery mixes to $103,000,000, and institutional mixes to $18,000,000, making a total of $421,000,000. In the past five years, the sales of mixes for home use have increased 30 per cent. In the next seven years, it is estimated that the increase will be from 50 to 60 per cent. Large increases are also anticipated in institutional and bakery mixes. At present there are some 90 different types of mixes on the market. By different types, we do not refer to different flavors or slight variations in the same type. There is probably an average of five different flavors or minor variations in each type, making approximately 450 to 500 individual mixes in the home field. The bakery and institu-

tional mixes probably increase this by 120, making approximately 670 individual mixes.

FORMULATION OF MIXES

To attempt to give information on 90 different types of mixes is far beyond the scope of this chapter. Consequently only the following will be discussed:

(1) formulas for a few simple basic mixes; (2) new methods of arriving at a formula for a prepared mix; (3) some of the essential functions and properties of the major ingredients going into prepared mixes; and (4) a few of the manufacturing processes.

The simplest and oldest formula is that of self-rising flour. This mix is still used extensively throughout the South. The formula is so common that it is essentially fixed in the Food and Drug Administration's Definitions and Standards of Identity for Cereal Flours and Related Products, Section 15.50:

> "(a) Self-rising flour, self-rising white flour, self-rising wheat flour, is an intimate mixture of flour, sodium bicarbonate, and the acid-reacting substance monocalcium phosphate or sodium acid pyrophosphate or both. It is seasoned with salt. When it is tested by the method prescribed in paragraph (c) of this section not less than 0.5 per cent of carbon dioxide is evolved. The acid-reacting substance is added in sufficient quantity to neutralize the sodium bicarbonate. The combined weight of such acid-reacting substance and sodium bicarbonate is not more than 4.5 parts to each 100 parts of flour used."

Expressed in terms of per cent, this formula is as follows:

Self-Rising Flour

Ingredients	*Percentage*
Flour	95.00
Soda	1.32
Anhydrous calcium phosphate	1.64
Salt	2.04
Total	100.00

The flour used is one suitable for biscuits and quick breads. The flour used in the majority of cases is bleached flour. There are three types of bleaches—namely: (1) chlorine; (2) chlorine dioxide; and (3) benzoyl peroxide. Any one of these may be used alone or in combination with the others. Usually the flour that produces the whitest color in the biscuit product is preferred. Chlorine dioxide and chlorine contribute to the development of the proper baking characteristics, such as volume, texture and grain, whereas benzoyl peroxide functions only to improve the color.

With reference to the different methods of producing mixes, there is a very wide variation in the types of equipment used. Anyone who has

a small batch mixer and scales can be in the mix business, by weighing the individual ingredients and mixing them with this very simple equipment.

Perhaps one of the earliest and simplest methods of continuous type mixing is in the case of self-rising flour.

Self-rising and phosphated flour may be made on a continuous basis by using Merchen Powered Scale Feeders. The ingredients used, namely

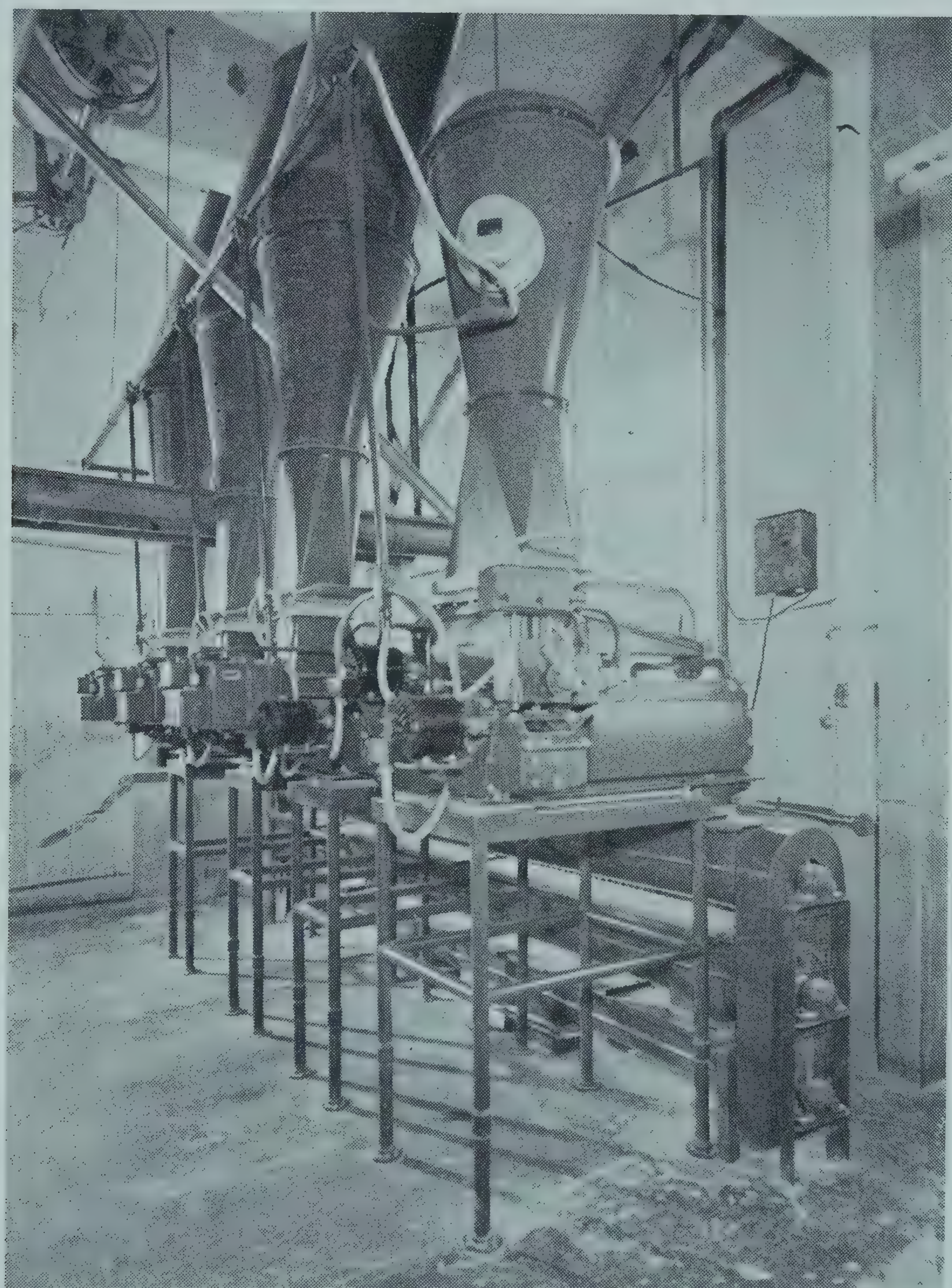

FIG. 81. MERCHEN FEEDERS USED IN BAKERY MIX PRODUCTION

flour, salt, soda, and phosphate are loaded into bins. Under each bin there is installed a Merchen Powered Scale Feeder. These feeders discharge into a common pick-up conveyor.

After the materials have been collected in the pick-up conveyor, they may pass through one or two more conveyors to insure proper mixing.

The pick-up conveyor may also discharge into a continuous mixer for mixing the materials, or the pick-up conveyor may discharge into a batch mixer which will thoroughly mix the materials. All three methods of mixing are satisfactory.

The manufacturer of the self-rising flour first determines at what rate he wishes to produce the finished product. The automatic measuring devices are then set so they will feed each ingredient at the desired rate. The scales are electrically interlocked so that if any one scale fails to function properly, it will shut down the entire system. If, for some reason, one of the ingredient bins should run empty, the system will also automatically shut down.

Let us now examine a number of household recipes for making biscuits. We find that there are three ingredients present in these recipes which are not found in self-rising flour, namely, shortening, milk and sugar. Calculate the amount of skim milk used to the equivalent in non-fat milk solids and add other ingredients which were not in the self-rising flour. This gives us a biscuit mix, the formula for which is shown below.

Biscuit Mix

Ingredients	*Percentage*
Flour	80.04
Shortening	12.67
Sugar	1.81
Salt	1.81
Anhydrous calcium phosphate	1.60
Soda	1.27
Non-fat milk solids	0.80
Total	100.00

This is a mix that is suitable for institutional use, yet not so high in milk solids that liquid milk cannot be added if desired. It is sufficiently high in milk solids to allow water to be used as a liquid. Of course the individual ingredients will vary slightly according to the formulator making up the mix. The non-fat dry milk, shortening and sugar are the ingredients responsible for richness and may be increased to change this characteristic.

In manufacturing biscuit mix, the simplest way is to use a batch mixer. The continuous method just described for self-rising flour can be used. All of the dry ingredients are mixed together first. The dry mix should be analyzed to determine the uniformity of the mixing process. There are four ways in which we may add shortening. One of the simplest ways is to use dry shortening, which usually is a mixture of approximately 65 per cent to 70 per cent shortening and the remainder non-fat dry milk. Dried shortening produces a biscuit which is slightly different from

one made with plastic shortening. It is somewhat moister and has a slight tendency to hold more water. Another way of incorporating the shortening is to spray it in. This can be done in a continuous stream or in a batch mixer. The third way is to use plastic shortening, employing high speed cutters that actually cut the shortening into the mixed ingredients as they are discharged from a conveyor at a constant rate. The plastic shortening is discharged into the cutter at a uniform rate. This produces a very simple system of continuous manufacture of biscuit mixes. A fourth way to incorporate shortening is to use a ribbon mixer fitted with wires.

Pancake mix is very widely used in the home and in institutions. The simplest form of a pancake mix would be a pure wheat pancake. The formula given below for a wheat pancake mix differs very little from the formula for the biscuit mix. The chief difference is that very coarse flour middlings that can be described as farina, and a small percentage of sodium acid pyrophosphate have been used. The farina middlings are incorporated to make the baked pancake more tender. The sodium acid pyrophosphate is used to slow down the rate at which the carbon dioxide is liberated. This slowdown of the evolution of the carbon dioxide is desirable for a pancake mix used in institutions where one mixing of pancake batter is made during the day and the cakes are continuously baked therefrom.

Pancake Mix Using All-Wheat Flour

Ingredients	*Percentage*
Flour	80.85
Dextrose	4.85
Salt	1.00
Non-fat milk solids	4.09
Shortening	3.24
Soda	1.22
Sodium acid pyrophosphate	1.01
Anhydrous monocalcium phosphate	.50
Recleaned fine middlings (farina)	3.24
Total	100.00

A good type of flour used is one that has a protein level of 10.0 per cent and ash of .42 to .44 per cent, bleached with chlorine to a pH of 5.4.

Wheat flour pancakes are rather limited in their distribution. The most commonly used pancake mix is one where the shortening is eliminated and corn flour is introduced to obtain tenderness. Cornstarch or rice flour are frequently used to obtain dryness in baked pancakes. A

small percentage of flours, such as rye, is frequently introduced to obtain flavor. The flour used is unbleached, as this gives much better keeping qualities than bleached flour.

Conventional Type Pancake Mix

Ingredients	*Percentage*
Flour	55.63
Corn flour	29.00
Rye flour	3.00
Rice flour	3.52
Corn sugar	2.00
Salt	3.07
Soda	1.78
Anhydrous monocalcium phosphate	2.00
Total	100.00

This type of pancake flour can be made in batch mixers, or in continuous mixers by simply extending the number of continuous feeders. Flavor may also be varied by using small percentages of dried buttermilk.

Buckwheat is another flour used for pancake purposes. Approximately 30 per cent buckwheat flour is used and the percentage of white flour and yellow corn flour are decreased. Quality control mill tests are run by making bakings immediately after the mix is made and pH tests are usually sufficient to insure uniformity.

Turning our attention to cake mixes, the reader would do well to refer to Military Specifications, Mil-B-3071B of April 8, 1958, and also Mil-C-35009A, giving the specifications for a Universal Cake Mix, which of course is a white cake mix.

Below is a typical formula for this white cake mix. It is to be noted in this formula that the flour has to be dried to a six per cent moisture and the shortening must be of the hundred-hour type according to the active oxygen method test. Both of these requirements are to insure improved keeping quality in the cake mix.

A distinctly different type of cake mix is known as a foam-type cake. This usually is a two-package mix. The egg albumen and a portion of the sugar and some anhydrous monocalcium phosphate are thoroughly mixed. A small percentage of flavoring (powdered vanilla) which usually constitutes about .1 to .2 per cent, may be added to this first part, or it may be omitted and used in the second part. This mixture, which we shall call *Part I*, is whipped either by hand or in a mixer to the right specific gravity. It is highly important that the albumen used be a fast whipping one. The particulars of these albumens are discussed in detail elsewhere in this chapter.

Universal Cake Mix

Ingredients	*Percentage*
Flour, 6 per cent moisture	37.51
Sugar	41.00
Shortening—100-hour	13.70
Egg albumen	3.00
Non-fat milk solids	2.50
Soda	.54
Sodium acid pyrophosphate	.15
Monocalcium monohydrate	.55
Salt	.90
Powdered vanilla	.15
Total	100.00

Angel Food Cake Mix

Ingredients	*Percentage*
Part I	
Egg albumen	31.00
Sugar, bakers' special	67.60
Anhydrous monocalcium phosphate	1.40
Total	100.00
Part II	
Flour	31.00
Sugar	68.06
Salt	.50
Cream of tartar	.30
Vanilla, powdered	.14
Total	100.00

The second part of this two-package mix contains flour, sugar, salt and cream of tartar. The type of flour desired has been discussed under the **Flour** section of this chapter. Where high protein flours are the only ones available, they can be materially improved by adding wheat starch to *Part II* to decrease the protein level.

It is very important that the package for *Part I* be moisture-proof in order to prevent caking. Some trouble has been experienced by certain organizations using inferior packages for *Part I*.

Below is the formula for an angel food cake mix. *Part I* constitutes 28 per cent of the mix and *Part II*, 72 per cent of the total mix. This is a very easy mix to manufacture, as all ingredients are in powder form. Some trouble at times is encountered by the egg-sugar mixture dusting. This can be cut down by using approximately .0300 of triethyl citrate as explained by Harrel and Baeder (1958) or by using 5 per cent pan-dried

albumen in the dried egg component of the mix. Triacetin will also reduce dusting. This dusting is very uncomfortable to the workers, and ingredient loss can at times run high. Sodium hexametaphosphate is an ingredient which can be incorporated at a level of about 0.2 per cent, giving very desirable properties of texture and grain and imparting some tenderness to the baked cake. The use of sodium hexametaphosphate is patented by Finucane and Mitchell (1954).

Pie crust mix is an unleavened type. Soft wheat flour, or a mixture of hard and soft wheat flours may be used. There are many different types of shortening which vary in their ability to impart tenderness to the pie crust. Consequently, considerable experimenting must be done to arrive at the proper shortening. The shortening, if sprayed on the flour and salt at a temperature just above the melting point of the shortening, will produce a mealy type of pie crust. Powdered shortening may be used, and this likewise will produce a very mealy form. When plastic shortening is cut in so that there are flakes of shortening, a flaky type of pie crust will result. It is important that the melting point of the shortening be such that the mix will not decrease in volume during the summer months, and yet will perform well during the winter months. It has at times been the practice to have one type of melted shortening for the winter months, and another of higher melting point when the product is prepared for summer use. This pie crust mix is very simple and a relatively easy one to make.

Pie Crust Mix

Ingredients	*Percentage*
Flour, unbleached	64.00
Salt	2.00
Shortening	34.00
Total	100.00

Six very elementary formulas have been presented. If the question was raised as to how these formulas were first secured it will be found that either well-developed bakery recipes or household recipes were converted to a dry mix on a percentage basis by using conversion factors. It is known that industry has certain improved ingredients which are not available to the housewife and small institutions. These ingredients include milk specially dried for bread production, shortening and emulsifiers specially designed for cakes, and leavening agents of a more suitable type. These have been substituted for home style ingredients, and improved mixes have resulted. By experimental evaluation of the percentage of many ingredients, the correct formula for the first prepared mix was evolved. After years of experience, accumulative knowledge has

permitted the easy and accurate formulation of cake mixes, bread mixes, pie crust mixes, etc., having unique properties. Notwithstanding this, reference is frequently made to established formulas and home recipes.

MIX INGREDIENTS

If all of the dry ingredients of a mix are weighed and combined, and liquid added as in the home, bakery or institution, the baking results are the same as if these dry ingredients had been weighed and a pre-mix made out of them.

It does not follow that if we allow the dry mix to stand and bake it at later periods, the baking results will be the same. We have deemed it advisable to present a detailed account of some of the properties of the major constituents. These constituents are: (1) flour; (2) leavening agents; (3) shortening; (4) eggs (albumen, yolk and whole); (5) milk; and (6) sugar.

The importance of flavoring, spices, etc. in mixes should not be minimized. Many flavoring ingredients such as vanilla, lemon, orange, etc., which are added in a very small percentage, have little effect on the baking, but flavors such as chocolate, cocoa, caramel, brown sugar, fruits, nuts and other heavy or solid ingredients at times affect the baking results, and changes in the formula must be made. With fruits, nuts, etc., it is frequently necessary to use more flour or a stronger type of flour.

In the baking industry, mixes are frequently made which consist of nothing more than two or three types of flour. These are properly called mixes. For example, a mix is made of 70 per cent spring wheat flour and 30 per cent rye flour for the production of rye bread. Another example would be a mix of 60 per cent hard winter wheat flour and 40 per cent whole wheat flour for the production of bread.

Flour[1]

Federal Definitions and Standards of Identity for wheat serve as a rather crude guide to the kind of flour which may be produced therefrom. Those wheats falling into the class "hard" are most suited for the production of bread flour or all purpose family flour, while those wheats which fall into the class "soft" are most desirable for chemically leavened products such as biscuits, cakes, cookies and crackers.

Within each class of wheat, as established by the Federal Standards, are a great many varieties which differ rather markedly in their performance characteristics. These differences are a result of plant breeding programs directed toward improvement of agronomical and/or functional characteristics of the grain or flour milled from that grain. Also, within

[1] This section was prepared with the assistance of Mr. D. G. Pratt.

each class of wheat, depending on soil nutrients and environmental or climatic conditions, rather wide ranges of protein content exist. These variations in protein content govern to an extent the end use of the flour milled from that grain.

It is possible to classify flour products milled from each of the wheat classes according to their usage. Tables 63, 64 and 65 show these uses. These tables furnish information for the selection of the best flours for any given mix. However, some mix manufacturers do not adhere to this classification strictly.

All flour is a finely ground product and by definition must pass a U. S. Standard 100 sieve (147 microns). In recent years, Wichser (1958) has pointed out that the flour, though it all passes through the Number 100 sieve, is not a homogeneous product. It contains particles which range in size from 1 to 147 microns and those particles falling within certain micron groupings are vastly different in their chemical make-up, as well as performance characteristics. It has become possible to fractionate flours in the sub-sieve range employing air-fractionation techniques. These fractions range from very high protein to very low protein products.

Since it is possible to fractionate flours in this manner, it is obvious that particle size will influence such things as free vs. adhered protein, chunky undamaged starch, fine starch particles, etc. Control of the quantities of these fractions present in any flour achieve a far greater degree of uniformity in the end quality and function of the flour.

Referring to Fig. 82, we see the breakdown of a hard wheat flour into four different fractions, resulting in the high protein fraction of 20 per

TABLE 63

COMPOSITION AND USES OF HARD SPRING WHEAT FLOURS

Protein, Per cent	Ash, Per cent	Bakery Products in Which the Flour is Used
12.5 to 12.8	0.42 to 0.44	White pan bread (both sponge and straight dough). Specialty and variety breads. Hamburger and wiener rolls. Yeast raised sweet goods. Soft rolls (Parker House type). Doughnuts, yeast raised. Hard rolls and hearth bread.
12.8 to 13.1	0.46 to 0.48	White pan bread (both sponge and straight dough). Hard rolls and hearth bread. Specialty and variety breads.
13.5	0.48	Hard rolls and hearth bread. Blender flour for coarse flour breads.
15.0	0.48	High gluten flour for Kaiser rolls. Italian, French and Jewish hearth breads.
15.0 to 15.5	0.70 to 0.74	Carrier flour used in making whole wheat, rye, specialty and variety breads. Blender flour used in mixes with rye flour for rye bread

TABLE 64

COMPOSITION AND USES OF HARD WINTER WHEAT FLOURS

Protein, Per cent	Ash, Per cent	Bakery Products in Which the Flour is Used
12.25 to 12.50	0.42 to 0.44	White pan bread, both sponge and straight doughs. Hamburger and wiener rolls. Soft rolls (Parker House type). Specialty and variety breads. Yeast raised sweet goods and doughnuts.
12.50 to 13.0	0.46 to 0.48	White pan bread, both sponge and straight doughs. Blender flour in some variety and specialty breads and rolls. Blender flour for chemically leavened biscuits, and muffin and waffle mixes. Heavy fruit cake mixes.
15.00 to 15.50	0.70 to 0.74	Carrier flour used in making rye, whole wheat, specialty and variety breads. Blender flour for baking powder doughnuts, and muffins and waffle mixes.

TABLE 65

COMPOSITION AND USES OF SOFT WHEAT FLOURS

Protein Per cent	Ash Per cent	Bakery Products in Which the Flour is Used
7.5 to 8.0	0.32 to 0.35	Angel food cakes. High ratio cakes and cookies (no spread). (Unbleached) High ratio spread cookies.
8.0 to 8.5	0.35 to 0.38	Layer cakes and pound cakes. Slightly rich wire-cut cookies (no spread). (Unbleached) Cracker topping.
9.0 to 9.5	0.39 to 0.42	Unbleached flour: General line of cookies. Pie crust. Blender flour in yeast raised fried goods. Cracker dough. Blender flour in yeast raised sweet goods. Sugar cones. Doughnuts. Bleached: No spread ice box cookies. Loaf cakes. Low ratio cup cakes. Lunch box cake items.
9.5 to 10.0	0.45 to 0.48	General purpose flour used much the same as the 0.39 to 0.42 ash flour.

cent; an endosperm chunk of 11.5 per cent protein; a cracker flour of 7 per cent protein and a cake flour of 6 per cent protein. This is quite unconventional since all of our textbooks and teachings have been that hard wheat flours are suitable for bread purposes and not cake production. The cake fraction made from hard wheat performs excellently in commercial cake baking.

Fig. 83 is the air classification or protein fractionation of what was considered some years ago to be an outstanding soft wheat cake flour.

The high protein fraction of 20 per cent is so strong that it can be used to strengthen bread flours. It can be blended with mixes to increase the baking strength of such mixes; in fact, it represents a reserve of baking strength which can be added at will to weaker flours.

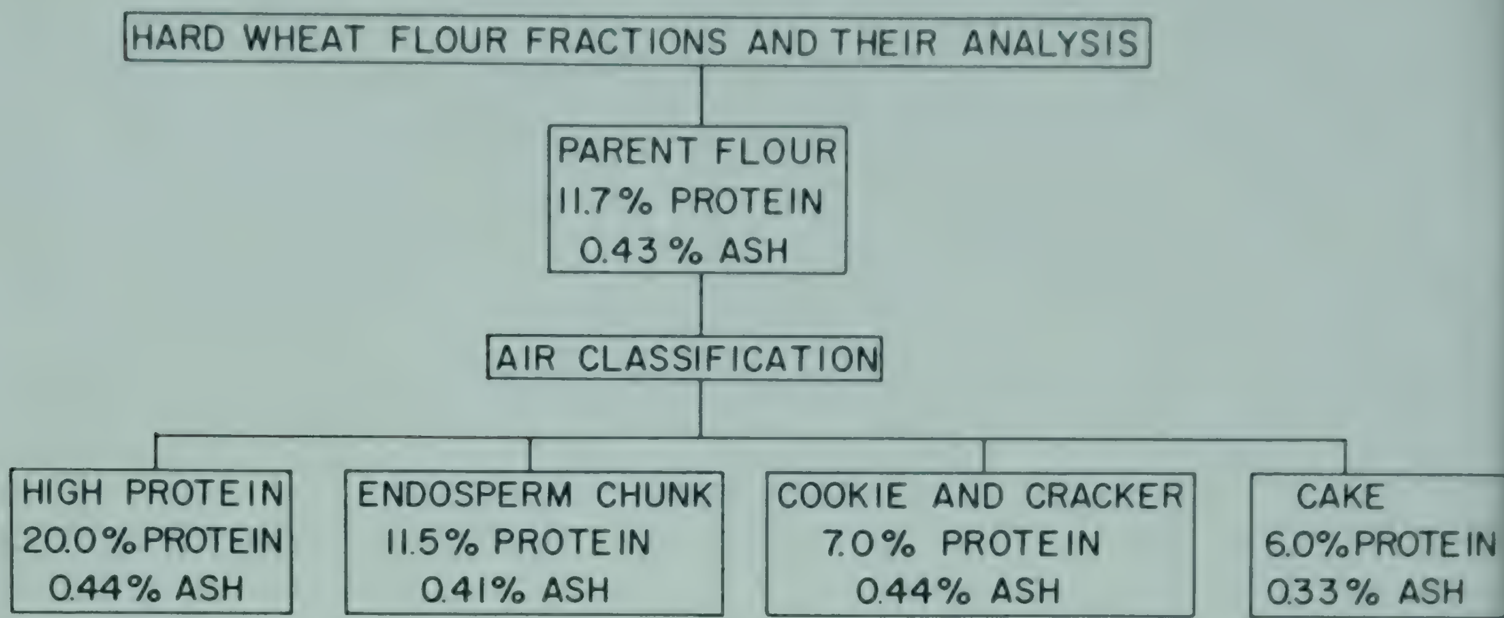

Fig. 82. Hard Wheat Flour Fractions and Their Analyses

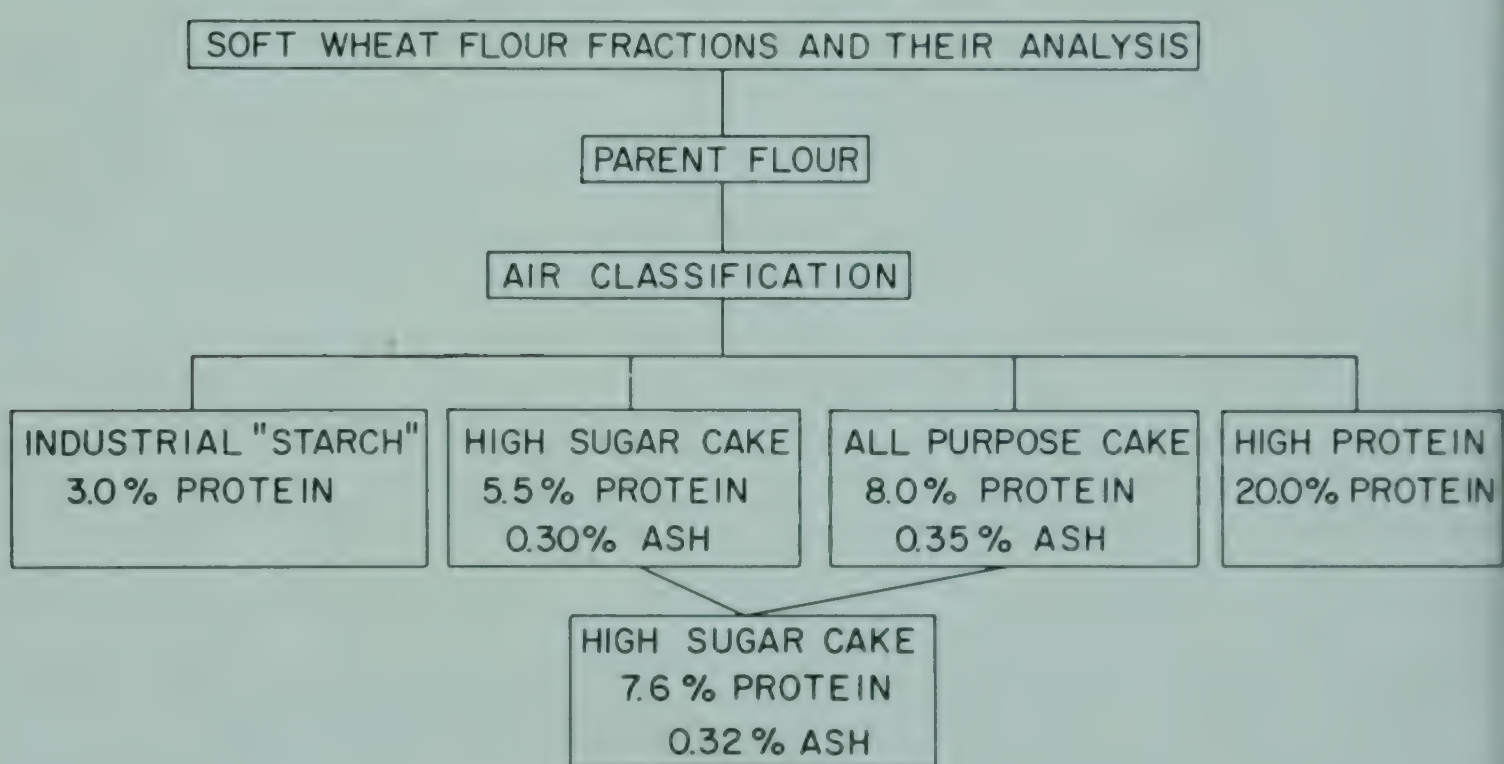

Fig. 83. Soft Wheat Flour Fractions and Their Analyses

The high sugar cake flour having a 7.6 per cent protein produces outstanding results in cake baking. It is particularly adaptable to angel food cakes where any surface fat is objectionable. This 7.6 per cent protein flour is low in surface fat, whereas the high protein fraction is higher in surface fat.

Fig. 84, on the left, shows an angel food cake made from the parent stock. On the right is shown an angel food cake baked from the 7.6 per cent protein flour. The 7.6 per cent protein flour has had certain un-

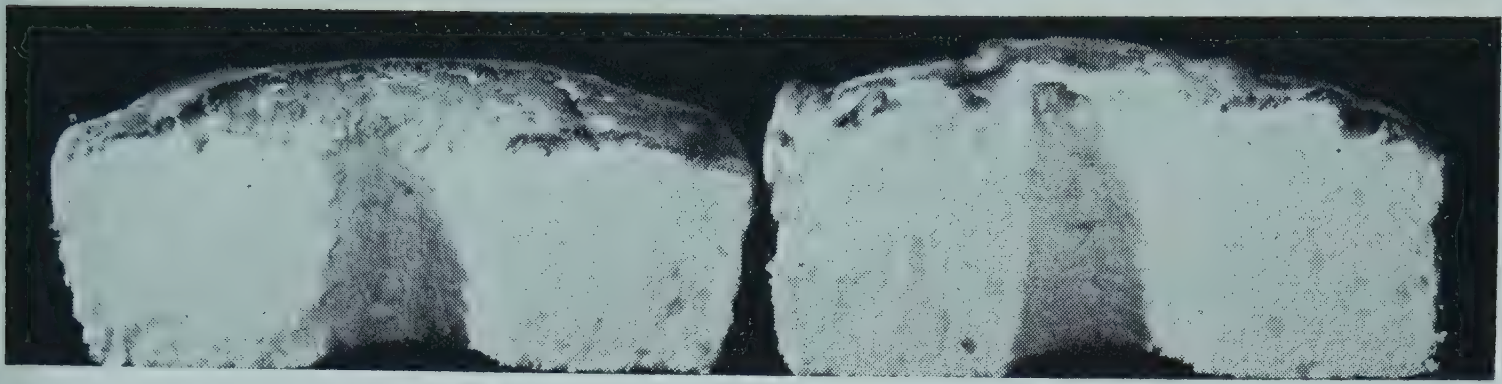

FIG. 84. ANGEL FOOD CAKES MADE WITH NORMAL FLOUR (LEFT) AND LOW PROTEIN COMPONENT OF AIR-CLASSIFIED FLOUR (RIGHT)

desirable flour particles removed from the parent stock by air separation.

It is possible through interpretation of the quality factors discussed here to define those characteristics which are desirable for certain uses.

Strong bread flours for use in hearth breads and hard rolls: high protein content, maximum gluten quality (mixing tolerance), great extensibility and resistance to extension.

Bread flours for commercial production: mid-range protein quantity, medium to strong gluten quality (mixing tolerance), medium to maximum extensibility and resistance to extension, mid-range enzymatic activity.

All purpose flours for family or home use: low to medium protein content, weak to medium protein or gluten quality, uniform specific volume (cup weight measurement), thus particle size is important; low to moderate enzymatic activity.

Cookie and cracker flours: low protein content (soft wheat), minimum of starch damage, low alkaline water retention capacity, maximum cookie spread, and low enzymatic activity.

Cake flour: low protein content (soft wheat), weak gluten quality, medium to large amount of starch damage (for soft wheat), high alkaline water retention (high range for soft wheat), medium-low enzyme activity, and uniformly small particle size.

An article discussing the maturing and bleaching agents used in producing flour points out that benzoyl peroxide has no maturing or oxidizing effects; its only useful purpose is that of a bleaching agent (Harrel 1952). Chlorine dioxide has an oxidizing effect and improves the texture and grain of bread mixes made from hard wheat flours. Treatment with chlorine is essential for the production of cake flours. Untreated cake flours may cause cakes to fall and have a concave top surface. Their texture and grain are highly undesirable, whereas chlorine-treated flours produce well-rounded cakes with excellent texture and grain, as well as improved eating qualities. The degree of chlorine treatment is usually determined by baking test results with the specific mix under question. The established level

of treatment is determined by holding the flour at a constant pH value. Treated or bleached flours usually have a shorter shelf life than untreated or unbleached flours; consequently in mixes such as pancake, unbleached flours are used in more cases.

Leavening Agents[1]

Leavening of cereal products by chemical rather than fermentative means dates from about 1842 when U. S. Pat. 2,816 was issued to Abel Conant (1842) for blending flour with tartaric acid, citric acid, alum, or any other known acid in the dry state; sodium bicarbonate, a common household article, was to be dissolved in water, sweet milk or any other liquid for making up the dough. As mentioned previously, in 1849, Henry Jones of England assigned U. S. Pat 6,418 to J. Fowler of Baltimore in which a balanced "self-raising" flour was prepared from an aged mixture of flour and tartaric acid ("to allow the water of crystallization which is always present in tartaric acid, to be absorbed, and for the flour to coat the acid") blended with sodium bicarbonate. Jones stated, "My invention consists in adding to a certain weight of flour such quantities of alkalies and acids, sugar and salt as shall, by addition of water only, enable such prepared flour to be manufactured into bread, etc., without the use of fermenting matter." Finally, early in the 1900's monocalcium phosphate, monohydrate, replaced tartaric acid and cream of tartar, and several patents proposed the addition of fats to self-rising flour, either directly or after imbedding the leavening therein. Thus, the concept of complete baking mixtures antedates by about 50 years the nation-wide acceptance of the product.

It was a natural step to extend the principles learned in self-rising flour manufacture to the prepared mix field but the demand for mixes has always been ahead of the art of ingredient manufacture. Leavenings were no exception. Monocalcium phosphate devoid of free phosphoric acid, sodium acid pyrophosphate and coated anhydrous monocalcium phosphate were the contributions of the leavening industry. Other industries developed stable dry milk and egg powders which would reconstitute rapidly and function properly. Special stabilized fats were compounded and highly specific emulsifiers were developed. Each item needed to be compatible with its neighbors within the package mix, yet be fully functional when brought into contact with liquid. A parallel development of moisture- and grease-proof packages was a major step in extension of shelf life. The Quartermaster Food and Container Institute was in a large measure responsible for encouraging the development of basic data and coordinating work so as to meet the demands of the Armed

[1] This section was prepared with the assistance of Mr. R. A. Barackman.

Forces for much needed improvements in baked products. The various industries met these needs, once the problems were defined. The present products offer a wide variety of very desirable baked goods for both home and institutional consumption.

Light, moist, flavorful and palatable baked goods are demanded by the consumer. Proper leavening of such products depends upon the expansion of preformed gas cells within a dough or batter upon the application of heat. Four sources are listed below. Carbon dioxide liberated from sodium bicarbonate is by far the most widely used source of leavening gas.

Leavening Agents for Prepared Mixes

Carbon Dioxide.—Baking acids which react with sodium bicarbonate to liberate gas.

1. Phosphates
   - a. Calcium phosphates.
     - Monocalcium phosphate, monohydrate.
     - Anhydrous monocalcium phosphate, coated.
     - Dicalcium phosphate, dihydrate.
   - b. Sodium phosphates.
     - Monosodium phosphate, anhydrous.
     - Sodium acid pyrophosphate.
     - Sodium aluminum phosphate.
2. Sulfates.
   - a. Sodium aluminum sulfate.
3. Organic acids.
   - a. Cream of tartar.
   - b. Tartaric acid.
   - c. Fumaric acid.
   - d. Glucono-delta-lactone.

Entrapped Air.—

1. Adjuncts which improve air retention in foam type products; listed in Table 68.
2. Homogenization of batters with air; these require a small amount of baking powder to boost the cake in the oven.

Heat Volatilized Solids or Liquids.—

1. Water vapor as steam not only assists in cell expansion, but cooks the product.
2. Ammonium bicarbonate—used extensively in cookie manufacture.
3. Acetone dicarboxylic acid—economically unfeasible; possible decomposition products would discourage its acceptance in food.
4. Hydrogen peroxide—no immediate application of this liquid phase

product is known; a catalyst to insure complete decomposition would be required.

Pressurized Gases.—No applications are known that utilize pressurized CO_2, N_2O or the Freon type aerosols.

Much as the controlled low moisture content of starch protects baking powder constituents from premature reaction, stability is likewise imparted to prepared mixes by adjusting the moisture content to below a critical level. Matz *et al.* (1955) concluded that maximum stability of such a preparation is obtained with flour at 7.4 per cent moisture content. However, there was some evidence that over-dried flours did not withstand storage when below 3 per cent moisture. An upper limit of moisture in the fully prepared yellow and white cake mixes was set at 8.8 per cent if extended storage was involved. Experience has demonstrated that each component in a dry mix must be below a certain critical moisture content since one component with loosely held moisture can trigger many interactions between ingredients and thus destroy baking efficiency and quality. For example, high moisture flour can set off the formation of free fatty acids and a premature reaction of the leavening ingredient which significantly depresses baking response. The remainder of the discussion on leavening agents will assume the use of ingredients which, when blended and properly packaged, have excellent stability and optimum baking response.

Sodium bicarbonate has been the source of leavening gas for baking products from the beginning with no practical substitute in sight. Extensive studies with both baking powders and prepared mixes have revealed that shelf life or leavening stability can be greatly enhanced by the use of a granular sodium bicarbonate, i.e., one that will all go through an 80-mesh sieve and not over 25 per cent through a 200-mesh sieve. Excessively coarse soda results in erratic bakeout, mottled crusts of cakes and brown spots on biscuits. A similar effect has been noted with coated soda. A powdered soda, 65 to 75 per cent through a 200-mesh sieve, is acceptable for self-rising flour, pancake flour mixes and some mixes that are soon used, but a granular soda is mandatory for those subjected to storage for six months or longer. The granulation of the baking acid is of equal importance. Any attempts to change solution rates by coatings on either reactant or by other means have resulted in less stable products or impaired baking response.

Potassium bicarbonate is sometimes substituted for the sodium salt in carefully designed baking powders that are to be used in sodium-free diets. However, as the potassium salt is highly hygroscopic and also imparts a bitter flavor, it has not been used by the prepared mix industry.

The rate of solubility of the baking acid as opposed to that of soda is

not controlled so much by particle size as by the method of manufacture. Yet, a certain maximum particle size is set, above which black specks would appear on biscuits and muffins. Studies in this specialized field have resulted in the tailoring of baking acids to fit the needs of the mix industry. Combinations of two or more baking acids are often used to accomplish specific leavening effects. Each of the baking acids listed previously and its reaction with sodium bicarbonate will be discussed in some detail. Mendelsohn (1939) should be consulted for manufacturing detail and chemical control.

Calcium and sodium phosphates have been widely accepted by the mix industry because of their purity, stability in mixes, versatility and reliable performances. They are also commercially available in quantity at a low cost. Most important of all, consumer demand for baked goods containing these products attests to their acceptance.

Monocalcium phosphate, monohydrate, $CaH_4(PO_4)_2 \cdot H_2O$ was first patented for use in self-rising flour by Horsford (1856) but lacked compatibility with flour until about 1904 when elimination of free acid from the product improved this factor. Anhydrous monocalcium phosphate, stabilized by means of coating (Schlaeger 1939 and 1939A, and Knox 1939 and 1939A) is the only major improvement that has been made in the manufacture of monocalcium phosphate. Whereas the monohydrate reacts rapidly with bicarbonate so that a large loss of carbon dioxide occurs during the early stage of the dough or batter development, the retarded solution of the coated anhydrous product during this same period saves carbon dioxide for leavening purposes (Barackman 1931 and 1954). This retarded gas formation over a 3- to 5-minute period has been particularly suitable for household mixes, especially when the more delayed reaction and added beneficial effects of the residual salts of other baking acids supplement its desirable characteristics.

Dicalcium phosphate, $CaHPO_4 \cdot 2H_2O$, was proposed as an acid which releases carbon dioxide from bicarbonate late in the baking process (Joslin and Ziemba 1955). Although it is used in some dry mixes in combination with a more active baking acid, its major application is in canned, refrigerated cake or other batters. Both systems require a special fat having enhanced air-emulsifying properties. This results in light, well-aerated batters which expand rapidly in the first steps of baking but need the late oven reaction of the dicalcium phosphate–bicarbonate combination.

Sodium acid pyrophosphate, $Na_2H_2P_2O_7$, is a very versatile material which can be adjusted in reactivity by manufacturing technique. A pyrophosphate can be made which reacts rapidly within a dough and is sensitive to oven heat, or it can be delayed in its reaction. These two extremes

of reactivity would be indistinguishable if tested by a simple solution of reactants in water (Barackman 1954). The dough system in which reaction takes place dictates the reaction level of the pyrophosphate to be selected. As an illustration, a pyrophosphate having a rapid response to heat is needed for cake doughnuts which are in contact with hot fat for about 90 seconds only. An intermediate activity satisfies the requirements for most household, bakery and institutional procedures. In this usage the pyrophosphate reactions are often adjusted with or augmented by the reaction of coated anhydrous monocalcium phosphate.

A pyrophosphate which has greatly delayed reaction is used in the preparation of specialty products such as canned biscuit doughs where inactive leavening is wanted before and during the canning process, yet regulated gassing within the can is essential to perfectly seal the container. Use is made of a secondary but highly important characteristic of pyrophosphate as illustrated by the reaction:

$$\begin{array}{ccc} Na_2H_2P_2O_7 + 2NaHCO_3 & \longrightarrow & Na_4P_2O_7 + 2H_2O + 2CO_2 \\ \Big\downarrow {\scriptstyle +H_2O\ (enzyme)} & & \Big\downarrow {\scriptstyle +H_2O\ (enzyme)} \\ 2NaH_2PO_4 + 2NaHCO_3 & \longrightarrow & 2Na_2HPO_4 + 2H_2O + 2CO_2 \end{array}$$

Data supporting the hydrolysis of acid or alkaline pyrophosphate to the orthophosphates are evident from the following:

	Fresh Dough	*2.5 Hrs.*	*5 Hrs.*	*24 Hrs.*
Pyrophosphate by analysis (Per cent)	90	30	18	2
Unreacted soda by CO_2 analysis (Per cent)	78	19	20	21
Biscuit crumb pH	8.5	7.7	. .	7.5
Biscuit flavor	Strong pyrophosphate	Sl. Saline	Saline	Saline

The pyrophosphatase enzyme activity of flour can influence these delayed reactions. It is significant that the flavor of the baked biscuits lacked the typical pyrophosphate flavor that was characteristic of a biscuit from the fresh dough.

Whereas commercial advantage is taken in refrigerated biscuit doughs of the delayed reaction of a "slow" acid pyrophosphate and its subsequent hydrolysis to the orthophosphate, this same sequence of reactions is deleterious to the stability of biscuit doughs that are not confined in a can and also of cake batter when held for long periods of time. Hydrolysis of pyrophosphate or orthophosphate results in a large CO_2 loss with an accompanying loss of baking properties. Blocking of the enzymatic re-

action has not yet been accomplished, except by partially baking or by freezing of doughs and batters.

Sodium aluminum phosphate, $NaH_{14}Al_3(PO_4)_8 \cdot 4H_2O$, is a special product which reacts late in the baking cycle when a sustaining action is wanted (McDonald 1951 and 1951A). This assists in the completion of bake-out with removal of under crust water. Cakes made with this product in combination with coated anhydrous monocalcium phosphate, maintain softness and a moist eating quality longer than if a pyrophosphate were used.

Sodium aluminum sulfate, $Al_2(SO_4)_3 \cdot Na_2SO_4$, in combination with monocalcium phosphate, monohydrate, sodium bicarbonate and starch are the components of baking powders which are used in commercial, institutional and household products. However, lack of compatibility of sodium aluminum sulfate with the ingredients of a dry mix, which results in an early development of rancidity and extensive lowering of baking quality, obviates the use of this baking acid although it is very economical.

Cream of tartar, $C_4H_5O_6K$, either alone or in combination with tartaric acid, $(CHOH \cdot COOH)_2$, enjoyed great popularity in the early days of leavening development, but today it is almost completely displaced by less costly ingredients that are capable of producing equal or better results.

Fumaric acid, $C_2H_4O_4$, is a recent newcomer in the leavening field. It is one component of a baking cream that also contains calcium sulfate, monocalcium phosphate, and starch. Claim is made that this cream is especially designed to stabilize the egg white foam in the production of angel food cake, and that it can replace cream of tartar. This applies chiefly in bake shop practice where fresh frozen egg white is used. There are no indications that fumaric acid or a blend of it with other acids is used for reaction with bicarbonate probably because of a cost factor.

Glucono-delta-lactone ($C_6H_{10}O_6$) is another acid having interesting reactions with bicarbonate, but its cost is prohibitive except when special effects are wanted. Its slow but continued reaction with bicarbonate can be used to modify a leavening action which needs to be increased in the intermediate temperature range. As an example, replacement of 10 per cent of the sodium acid pyrophosphate with glucono-delta-lactone in a doughnut mix has been found to prevent excessive grease soakage. Where cost is not a factor, as in convenience items for the armed forces, possible usages may be found, as in "instant bread" (Miller *et al.* 1958). In this application most inorganic baking acids react during the rather severe dough processing steps and result in objectionable flavors. Glucono-delta-lactone seems to overcome both of these limitations.

Table 66 summarizes the present day prepared mixes that are leavened with carbon dioxide from bicarbonate and indicates the baking acid or acid combinations that are used. The other sources of leavening gases will be discussed briefly. Table 67 lists the commonly accepted neutralizing values of two baking acids.

TABLE 66

PREPARED MIXES
Common Household Products, 1952–1958

	Acid Code[1]
A—Self-rising Products	
Self-rising flour	2, 3, 8
Self-rising cornmeal whole ground and degermed	2
Self-rising cornmeal mix (less than 15 per cent wheat flour)	2
Self-rising pancake mix	2, 2 + 8
B—Semi-sweet Products	
Corn muffin mix (over 40 per cent wheat flour)	2, 1
Biscuit mix (household)	2, 1
Biscuit mix (institutional)	3
Muffin mixes, specialty products (orange, raisin, etc.)	1
C—Cake Mixes	
White	1, 2, 3
Yellow	1, 2, 3
Devil's food or chocolate	1, 2, 3
Spice	1, 3
Gingerbread	1, 3
Brownie or fudge	3, 6, 9
Cup cake	3
Specialty cake mixes	5, 9
Date bar	6, 9
Specialty cookie mixes	6, 9

[1] Acid Code (baking acids which react with sodium bicarbonate to furnish CO_2).
1—Anhydrous monocalcium phosphate, coated + sodium acid pyrophosphate.
2—Anhydrous monocalcium phosphate, coated.
3—Sodium acid pyrophosphate.
4—Sodium acid pyrophosphate + monocalcium phosphate, monohydrate.
5—Sodium aluminum phosphate. (100 N.S.)
6—No baking acid.
7—Dicalcium phosphate, dihydrate + anhydrous monocalcium phosphate, coated. (33 N.S.)
8—Monocalcium phosphate, monohydrate. (80 N.S.)
9—Sodium bicarbonate only.

Air, which is beaten into the foam type of cake batter, along with steam accounts for nearly all the volume that is attained in angel food cakes and the like. Table 68 lists chemical coagulants for egg white as well as acidifying agents that adjust the pH of the baked product. In some cases when excess acid is present, a minor amount of sodium bicarbonate adjusts the pH to an acceptable flavor level and also furnishes some reserve carbon dioxide. Recently exceptional whipping properties have been imparted to dried egg white through improved processes of manufacture. Some specialty products such as chiffon or sunshine cake mixes rely upon a combination of foam and leavening from bicarbonate, the foam being folded into a shortened batter.

Water, when volatilized as steam, plays an obvious role, not only as

TABLE 67

NEUTRALIZING STRENGTH OF BAKING ACIDS IN COMMERCIAL USAGE

Anhyd. Monocalcium Phosphate, Per cent	Sodium Acid Pyrophosphate, Per cent	Neutralizing[1] Strength
100	..	83
90	10	83
80	20	81
70	30	78.5
60	40	76
50	50	73
40	60	70
30	70	70
20	80	70
10	90	70
..	100	72

[1] Pounds of bicarbonate which will be neutralized by 100 lbs. of acid.

TABLE 68

LEAVENING AGENTS IN ANGEL FOOD CAKE MIXES

A package—contains egg white, sugar, coagulant, these to be whipped in water to a light foam.[1, 2]
Glassy phosphate, usually sodium hexametaphosphate.
Monosodium phosphate.
Anhydrous monocalcium phosphate, coated.
Monocalcium phosphate, monohydrate.
Cream of tartar.
Tartaric acid.

B package—contains flour, sugar, leavening agent, these to be folded into the whipped foam of "A."[1]
Cream of tartar.
Tartaric acid.
Monocalcium phosphate, monohydrate.
Anhydrous monocalcium phosphate, coated.
Sodium bicarbonate (neutralizer of excess acidity and for pH adjustment).

[1] Salt is present in either the *A* or *B* package.
[2] Some *A* packages do not contain a coagulant for egg white.

a leavening agent but as a cooking medium to "set" cell structure. Much as water is the only heat volatilized liquid, ammonium bicarbonate or sesquicarbonate, NH_4HCO_3 or $(NH_4)_2CO_3 \cdot NH_4HCO_3 \cdot H_2O$, is the only commonly used solid which is heat-volatile. Commercial cookie baking processes use it in combination with sodium bicarbonate to obtain slightly alkaline baked products. Monocalcium phosphate, monohydrate, in very small amounts stabilizes pH. These reactants are usually dissolved and added in separate portions of the water to assure complete solution and even distribution, since baking time is as short as $2^1/_2$ to 3 minutes. Because of these mechanical limitations and the deliquescent property of the solid ammonium carbonates they are not used in dry mixes.

Pressurized systems in which air is forced by continuous operational

facilities into batters result in homogenizing actions; these are in use in large scale operations. However, there has not yet appeared on the market for home usage a pressurized cake batter or like product.

Equations for the reactions of baking acids with bicarbonate and the residual salts that are formed can be chemically defined from reactions in boiling water (Mendelsohn 1939), but only circumstantial evidence is available that similar reactions occur within a product during the baking process. Undoubtedly some direct reactions take place between acidic and basic components when water first contacts the dry materials, but as mixing of the dough is continued, water becomes "bound" through hydration of starch and protein and the free water that remains becomes saturated with other ingredients such as sugar. Partial control of solution rate by regulating particle size of bicarbonate and of baking acids has already been discussed and is of importance in the formation of alkaline and acid areas which through a process of diffusion react to release carbon dioxide. Undoubtedly protein and starch form massive complexes with the nearest leavening component. Then, add the accelerating influence on mobility of ions by increased temperature during the cooking process and a rather complex, dynamic condition can be visualized. Illustrations which support this view are spots on the crusts of biscuits where the surface dries and blocks diffusion. Brown spots originate from too coarse a soda which, because of alkalinity, caramelizes organic matter. Black spots originate from too coarse a baking acid which, because of a high concentration of acid, chars organic matter. Other evidence is noted when the sliced surface of biscuit crumb is wet with an acid-base indicator. Alkaline centers, 8 to 9 pH, shade off to acid areas, 4 to 6 pH, but when crumb pH is measured a neutral 7.2 pH is obtained.

The mass effect which results in a balanced reaction in baking products is attained through the use of baking acids at their stipulated neutralizing strength. This is defined as the pounds of bicarbonate which will be neutralized by 100 lbs. of baking acid. However, cake mix formulations are not bound to the theoretical neutralizing strength. A limited excess of baking acid can be used to obtain certain improved characteristics as in white cake mixes; or an excess of bicarbonate, as in devil's food mixes, will bring out certain flavor and crumb color characteristics.

The quantity of carbon dioxide which is formed from the reaction of the two major baking acids with sodium bicarbonate is shown in Fig. 85. A typical white cake mix into which water and egg white were mixed for two minutes was used. The percentage of the total carbon dioxide released at various temperatures are plotted against time. No practical means have been proposed for measuring the increase in gas release as the temperature of a batter enters the baking range. It was thought that

the family of curves as obtained with separately run batters, but having all ingredients adjusted to the selected temperature, would at least indicate sensitivity to heat before coagulation sets in. The circled five-minute values would then describe the effect of temperature on the gas-forming

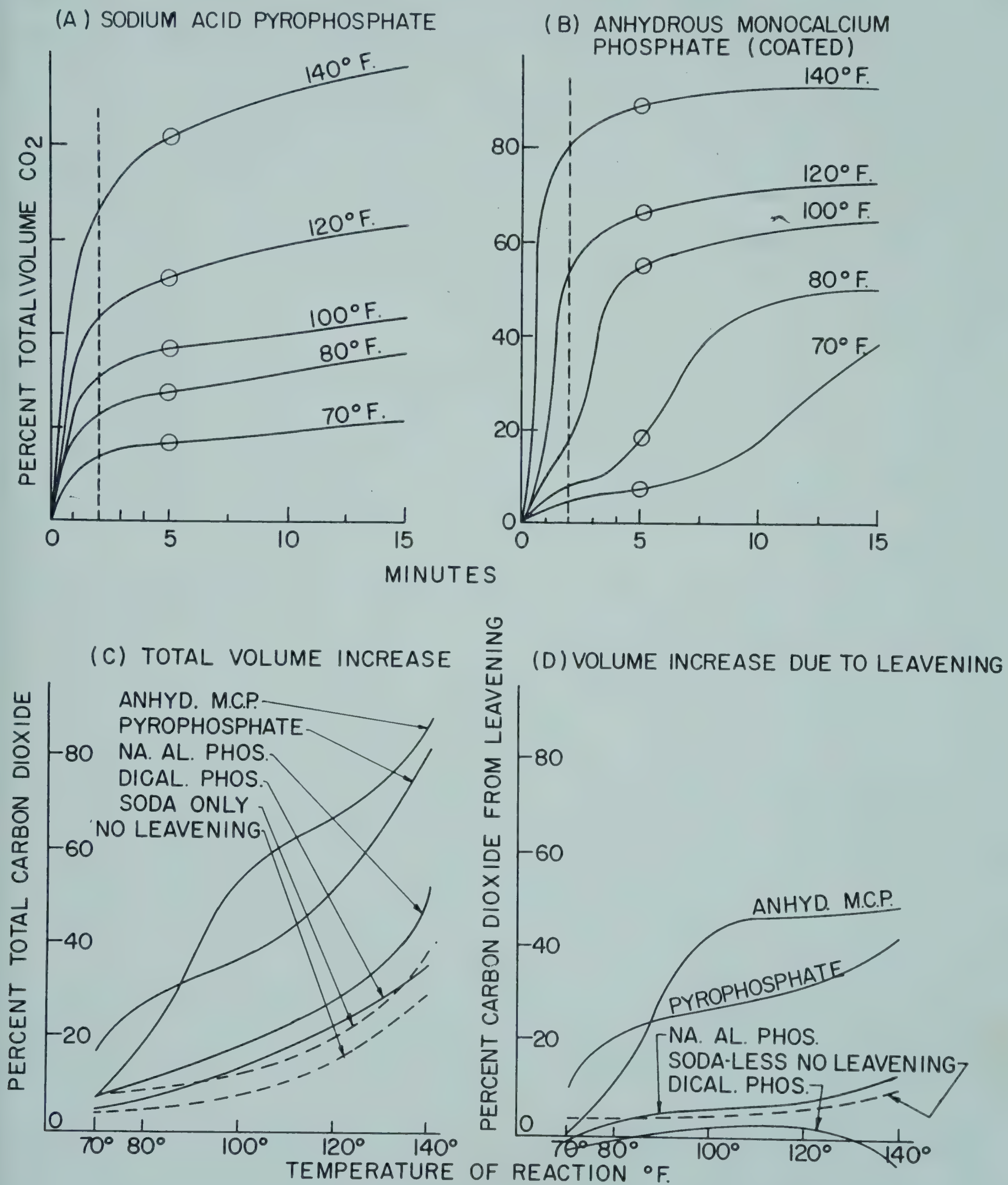

Fig. 85. Leavening Reactions at Various Temperatures

system. These are replotted in another part of Fig. 85. Also included are similarly derived curves for sodium aluminum phosphate, dicalcium phosphate, no leavening and soda only. It is significant that the "no leavening" curve shows a positive increase in volume as temperature increases.

By subtracting such values from total volume curves, the carbon dioxide which originates from the reaction of bicarbonate with each baking acid is obtained. From these it is indicated that reaction with anhydrous monocalcium phosphate, coated, becomes activated between 80 and 100°F., whereas pyrophosphate is delayed in reaction after an initial carbon dioxide release and becomes active above 120°F. On the other hand, sodium aluminum phosphate and dicalcium phosphate, dihydrate, do not appear to be active under 140°F., but baking experience indicates an earlier completion of gas release with sodium aluminum phosphate but not with dicalcium phosphate. Thus experimental data are lacking in the range of temperature above 140°F. and in the final stages of baking when steam completes the release of carbon dioxide.

Shortening[1]

Nearly all baked products produced from cereal grains require varying quantities of fats or oils of one type or another in the formulation. Requirements for fat are established by the desired physical properties of the finished food product. Fats contribute to the tenderness, crispness, softness, volume and to all other aspects connected with the texture of the cereal food.

The development of pre-fabricated baking mixes has brought into focus many problems connected with the use of fats and oils which formerly were unrecognized. Baking mixes for prolonged storage requirements place a high premium on keeping quality of the fat. There are two aspects to the keeping quality problem; first, that associated with flavor of the fat ranging all the way from the development of slightly offensive flavors sometimes called by fat and oils technologists, "reversion," to complete oxidative rancidity, and second, the stability as expressed in terms of continued and undiminished baking performance values brought about by both chemical and physical stability of the fat when dispersed in the baking mix.

Only a decade ago, very little was known concerning the baking stability problem of mixes. Rapid advances have been made. However, there still remains many baking problems with which certain types of fats are associated.

Oxidative rancidity still remains as a major problem of the prepared mix manufacturer. The widespread use of antioxidants, or "oxygen interceptors," has resulted in a major improvement and has greatly broadened the scope of the mix manufacturer in selection of shortenings. No longer is the manufacturer of prepared mixes tied to hydrogenated cottonseed oil shortenings, but he is now in position to make use of products of widely

[1] This section was prepared with the assistance of Mr. G. T. Carlin.

varying formulations manufactured from lard, beef fat, hydrogenated cottonseed oil and hydrogenated soybean oil.

It is apparent from Table 69 that the antioxidants now in common use are quite effective inhibitors of oxidative rancidity. This problem is no longer as troublesome as it was formerly to the manufacturer of fatty foods requiring prolonged storage life.

TABLE 69

EFFECTIVENESS OF CERTAIN ANTIOXIDANTS[1]

Fat	Stability,[2] Hours
Prime steam lard	3– 8
Deodorized prime steam lard	8– 10
Prime steam lard (plus gum guaiac and citric acid)	20– 35
Deodorized prime steam lard (plus gum guaiac and citric acid)	25– 50
Prime steam lard (plus NDGA and citric acid)	30– 40
Prime steam lard (plus propyl gallate and citric acid)	20– 50
Prime steam lard (plus BHA and citric acid)	25– 50
Prime steam lard (plus BHA, BHT and citric acid)	25– 50
Prime steam lard (plus NDGA propyl gallate and citric acid)	45– 90
Prime steam lard (plus BHA, propyl gallate and citric acid)	50– 90
Prime steam lard (plus BHA, BHT, propyl gallate and citric acid)	50– 90
Hydrogenated lard (not stabilized)	30– 45
Hydrogenated lard (plus BHA, NDGA and citric acid)	100+
Hydrogenated cottonseed oil (B and C type)	80–120+
Hydrogenated soya oil (B and C type)	120–180+
Hydrogenated shortening containing lard and cottonseed oil (plus BHA and citric acid)	120–160+

[1] Quantities added in accordance with levels permitted by U. S. Department of Agriculture.
[2] As determined by the Swift active oxygen method.

Certain precautionary measures are essential when selecting the proper antioxidant for the prepared mix trade. Gum guaiac, for example, will develop a purple color when exposed to certain peroxide-decomposing enzymes. Since flour contains peroxidases, the use of gum guaiac would cause possible color trouble if used in prepared mixes. Propyl gallate also develops color reactions under certain conditions. It turns black if exposed simultaneously to iron rust and moisture. Both NDGA and propyl gallate produce green discolorations when mixed with egg yolk. As yet, no color reaction difficulties have been noted when using BHA, BHT and citric acid. The problem of color control is important. Mix manufacturers who add their own antioxidants to liquid fats should be especially cautious not only in the selection of the antioxidant but also in removing sources of metallic contamination. The use of acidic synergists (citric acid and phosphoric acid) will aid in inhibiting color development.

Prepared mixes often contain natural antioxidants. Unbleached flours used in pie crust mix greatly extend the shelf-life of the shortening used in the mix. Ginger and other spices used in spice cake mixes are powerful

antioxidants and appreciably increase rancidity resistance. Sugar, acid phosphates, lecithin and several other ingredients used in mixes possess antioxidant properties.

Certain baking mixes enable the measurements of "shortening value," in terms of either crispness or tenderness of the final baked item. Crisp products, such as pie crust, crackers and cookies are representative products within this category. Shortening values of fats in crackers and pie crust have been studied by many investigators with general agreement on the relative effectiveness of the fat. Subjective evaluations will commonly give ratings of about 80 for hydrogenated lard, 77 for hydrogenated vegetable shortening, 80 for beef fat, and 65 for liquid vegetable oil when pie crusts made with lard and given an arbitrary rating of 100. This would seem to indicate the superiority of lard as a contributor of tenderness or shortness to crisp products. The same tendency is apparent in baking powder biscuits, but to a lesser degree.

Creaming or emulsification properties of fats determine to a major degree their usefulness in cake mixes. Included in these properties is the ability of the fat to disperse air throughout an aqueous batter in a finely divided and stable state. The emulsion resulting when fats are mixed in aqueous batters will determine the final character of the baked product.

Lard has always suffered when its creaming properties are compared with those of shortenings produced from other fats. The crystalline structure of the lard responsible for its superiority as a shortening for pie crust and biscuit mixes, is not conducive to suitable creaming and emulsification in aqueous batters; for example, layer cake mixes. The problem was not completely understood until x-ray techniques were developed for elucidating the crystalline structure of the plastic fat.

In 1948 a major "break-through" was made in the understanding and evaluation of the effect of fat crystals on creaming quality. This was brought about by resorting to chemical rearrangement techniques which altered the structure of fats—particularly of lard—to enhance emulsification and creaming properties. These techniques were developed around the use of either sodium methoxide or stannous catalytic agents for purposes of securing reorientation of the fatty acids on the glyceride molecule. It is believed that such rearrangement results in both intra- and inter-esterification of the fatty acids contained in the glyceride molecule. As a result of these procedures, a high degree of interchangeability has been developed between the various fats and cake shortenings are now manufactured from the entire range of available domestic fats; namely, tallow, lard, soybean oil, cottonseed oil, peanut oil and the like. The evidence is overwhelming that the structural arrangements of the glyceride

molecules have great influence on the type of crystal produced during solidification of shortenings. It is also well known that the type of crystal influences creaming and emulsification properties to a major degree. The ability to control the crystalline property of fats produced from varying raw materials is perhaps the most important development in shortening technology during the past 25 years.

Fats do not "emulsify" in stiff doughs, for example, bread, pie crust, cracker and biscuit doughs. Photomicrographs of doughs of this type will show a rather coarse dispersion of fat alongside the gluten strands of the flour. In such products, emulsification is of little importance. In aqueous doughs and batters, however, fats must disperse themselves in the form of an extremely fine emulsion (usually fat in water emulsion) if the baked product is to be of maximum tenderness, fluffiness and symmetry. Failure to achieve a uniformly fine emulsion when attempting to distribute the fats in aqueous batters, will produce defective finished baked products of coarse grain, poor volume, poor symmetry and altogether improper palatability.

The emulsification phenomenon is made even more complex by the necessity of emulsification of gases. The air creamed into an aqueous batter is usually held in a suspended state by the fats used in the mix. These air spaces serve as collection points for gases later generated within the baking cake mix from the chemical leavening agent. Such aggregations of air cells are held in suspension by the fat used in the mix with the fat influencing greatly the interfacial tension between the surface of the air bubble and the liquid fraction of the batter. Not enough information is at hand concerning the relation between interfacial tension of fats and liquid and of the relation between the interfacial tension of the air cell-liquid interfaces. Measurements of this type will serve as a fundamental area of research to establish the most desirable conditions. Present methods lean heavily upon baking tests as a sole means of evaluation.

Nearly all fats (with the exception of non-rearranged lard) have some ability to emulsify in an aqueous batter. They also have some ability to suspend air or gas within the body of the fat globule during the emulsification procedure. None of the fats however, is sufficient in itself to produce the effect desired by the modern cake mix manufacturer. The industry now leans heavily upon several additives which are known commonly as "emulsifying agents." These emulsifying materials include the following compounds:

Mono and diglycerides	Polyoxysorbitan monostearate
Lactylated mono and diglycerides	Polyoxyethylene stearate
Lecithin	Sorbitan monostearate
Hydroxylated lecithin	Sorbitan monooleate

Mono- and diglycerides are the most widely used additives for prepared mixes of all types. There are many different variations of mono- and diglycerides each of which possesses specific properties of emulsification and air retention. Mono- and diglycerides vary in hardness dependent upon the hardness of the shortening or fatty base stock used in their manufacture. They also vary in the selection of fatty acid chain length, ranging in type from fatty acids of twelve carbon chain length to fatty acids of a chain length of 22. It has been proven conclusively that the functional properties contributed by mono and diglycerides to cake mixes differ widely and that consideration must be given to these factors if suitable products are to be obtained with particular respect to long-term storage.

Lactylated mono- and diglycerides are manufactured by combining with the normal mono- and diglyceride one or more molecules of lactic acid. This complex ester is formed usually by direct esterification of lactic acid, fatty acids and glycerol.

Again, the functional properties of the final product will be greatly influenced by the chain length of the fatty acid, the melting point of the respective fatty acids and the relation between quantities of fatty acid vs. lactic acid used in the formation of the complex. Glyceride esters of this type usually produce fast whipping very light cake batters. Such esters, however, are subject to hydrolytic decomposition and for this reason, cannot be recommended for mixes requiring extraordinarily long or severe storage properties.

The polyoxyethylene sorbitan esters cover a wide range of materials dependent first upon the molecular weight of the polyoxyethylene moiety and the molecular weight or chain length of the fatty acid contained in the molecule. These compounds will produce widely varying emulsification and whipping properties dependent upon both their concentration and composition.

Sorbitan-fatty acid esters also are produced in varying molecular weights and in varying sorbitan-fatty acid ratios. These materials also serve to enhance emulsification properties of fats and also the air suspending properties, when used in aqueous batters. The position of these esters with reference to the food regulatory officials is not entirely clear, and for that reason their use has been restricted by members of the prepared mix industry.

Sorbitan-fatty acid esters have limited use in shortenings designed for use in batters and doughs. One important characteristic of these compounds is that they have a somewhat detrimental effect upon the ability of shortening to suspend air, and have a definite effect upon the tendencies of a product to stick to its baking pan. Lecithin also is used in combina-

tion with some of the other emulsifying agents to produce more body in cakes of undue fragility.

Manufacturers of cake mixes have learned that original baking properties are somewhat transistory and that the quality of the finished cake mix slowly deteriorates upon prolonged storage. This is especially true when storage temperatures and humidities are high. Numerous factors are thought to contribute to this deterioration; for example, moisture content of the flour, lipase action of the flour, type of baking powder, type of shortening, and type of egg product (if any) used in the mix. Attempts to dry flour to a moisture content of 4 to 8 per cent have been made in an effort to prolong the shelf life of the mix. Various methods have been suggested to measure and reduce the lipase action of flour.

Recent work indicates that shortening is the dominant factor in cake mix stability assuming, of course, moisture content is reasonably low (4 to 8 per cent) and that the baking powder is of a suitable type. A good cake mix shortening should possess the following properties:

1. Quick and easy aeration when subjected to a minimum of mixing. Batter specific gravity offers a convenient method for measurement of this property.

2. Dry, non-greasy body to prevent undue grease soakage and clumping of the cake mixture. The tolerance of the shortening to over-mixing when blending the cake mix ingredients should be as wide as possible.

3. The shortening should be bland in flavor and should remain bland after prolonged storage.

4. The final mix should withstand prolonged storage at temperatures as high as 100°F. without serious impairment of cake volume, cake texture, or any other measurable baking characteristic.

5. The cake mix should perform well when mixed by hand and should not require mechanical mixing.

Pie crust mixes are manufactured from a wide variety of shortenings including all-hydrogenated, prime steam lard (both normal flavor and deodorized) and partially hardened (fractionally hydrogenated) shortenings. The type of shortening is determined to a great extent by mixing methods used by the mix manufacturer and by the total fat content of the mix.

It is quite possible to use either melted or semi-solid fats in pie crust mixes providing the mixing equipment is suitable and mixing time and temperatures are closely controlled. Tendencies toward fat soakage of flour and pasting make such assembly methods extremely hazardous. If flour soakage becomes too great suitable pie crusts cannot be made from the finished mix.

Plastic shortenings including plasticized lards are used for pie crust

mixes. Attempts are sometimes made to "shatter" or disperse these fats throughout the mix in the form of fine granules. Various mechanical contrivances have been developed to secure this effect. Such devices require close adaptation of the physical characteristics of the shortening to meet equipment and temperature requirements. Small deviations in shortening texture may lead to important quality differences in crusts assembled by such methods.

The flavor of the shortening is of paramount importance to the manufacturer of pie crust mixes. Many manufacturers prefer completely deodorized, tasteless fats and oppose the use of high percentages of soybean oil because of the possibilities of flavor reversion. Conversely, many other manufacturers prefer pie crust flavors produced by steam rendered lard and attempt to control the flavor by this method. Still other manufacturers prefer the texture of lard but require complete deodorization.

Hot roll mixes, sweet yeast dough and yeast raised doughnut mixes have become increasingly popular. Shortenings of high mono- and diglyceride content seem to be preferred for such use because of the increased tenderness imparted to the finished product. Irregularities in the fermentation and dough absorption may also be controlled more closely through the use of mono-and diglyceride shortenings. Oils and extremely low-melting point fats should be avoided for use in yeast-leavened mixes because of their adverse effect on the gas retention properties of fermenting dough and subsequent reduction of volume in the finished product.

All yeast-leavened products are influenced in quality primarily by the grade of flour used in the formulation of the mixes. Sweet yeast dough mixes and bread mixes are influenced greatly by this important factor. The shortening used in the formulation, however, can also be an important factor in the regulation of the final baked product. For example, bread and sweet dough mixes formulated around a shortening of high mono- and diglyceride content will require less fermentation and less manipulation than will mixes formulated from purely triglyceride fats. The amount of monoglyceride suitable for use in such mixes, is in the area of 8 to 10 per cent of the weight of the shortening used in the formulation. Higher levels of monoglyceride may also be used. However, problems of excessive tenderness and excessive softness of the final baked product, will be encountered if the monoglyceride level is continuously increased.

The mechanism of the monoglyceride reaction in yeast-leavened products is entirely different from the emulsification phenomenon previously described for cake mixes. Very strong evidence exists which indicates that monoglycerides form either a chemical combination or a type of chemical complex with the amylose fraction of wheat flour during baking

providing the sugar concentration of the dough is not too high to block the reaction. Such a combination with amylose greatly influences the tenderness and softness of the final baked product. It also influences in a most beneficial manner, the keeping quality of the final baked product. For these reasons, shortenings of high monoglyceride content are preferred for yeast-leavened mixes.

There are numerous types of doughnut mixes ranging from mechanically made cake doughnuts of varying richness to hand made crullers, yeast raised doughnuts, and even French doughnuts.

Each doughnut manufacturer has preferences concerning the type of shortening used. Shortening has a profound effect upon the tenderness, symmetry and fat absorption properties of all doughnuts. Manufacturers of low-cost (lean) cake doughnuts for high speed automatic production, invariably make use of liquid oils, such as either soybean oil or cottonseed oil as the shortening agent for the doughnut flour. Such oils are productive of a tough internal structure but also are helpful in the production of suitable symmetry in the final doughnut. Because of the tough structure, the mechanically formed doughnut will absorb but small quantities of fats during frying.

Plastic shortenings, on the other hand, will produce higher shortening effects in the doughnut mix which manifests itself in added tenderness and added fat absorption. The manufacturer producing the "cake-type" doughnut who is not worried by the desire to secure minimum costs, will automatically use the plastic type shortening in preference to oil.

Doughnut manufacturers also use shortenings of high monoglyceride content to produce additional tenderness when desired. It must be emphasized, however, that tenderness and fat absorption go hand in hand and that the more tender the final doughnut, the higher will be its fat absorption. For this reason alone, there is a wide divergence of opinion concerning the ideal shortening for doughnut mixes. Inasmuch as the fat content of doughnut mixes is low, it is of utmost important that the fat be selected in accordance with the exact characteristic which is desired in the finished product.

There are numerous miscellaneous mixes making use of shortening, such as specialty pancake and waffle mixes, corn meal mixes of varying types, muffin mixes and the like. In the production of rich pancake and waffle mixes, shortening is used at a relatively high level. This not only improves tenderness of the final product, but also improves release of the item from the waffle iron or from the griddle. Fats usually used for the purpose are of the same type suggested for either pie crust or biscuit mixes. There is no need for creaming properties or for high monoglyceride content in fats used for this purpose. Indeed, if such fats are

used, the resulting product will prove excessively tender and cause much difficulty through sticking to the waffle iron or griddle.

Corn meal mixes place a very high premium on stability of the fat. Much corn meal is high in lipase activity and is also inclined to become musty or slightly rancid in itself. The shortening will have great influence on the stability of corn bread mix and for that reason, high stability shortening should be used. It is a proven fact that corn bread mix will have much greater keeping quality when made with fairly high levels of hydrogenated shortening as the shortening agent.

Muffin mixes cover a wide area. Some of the mixes are similar in character to baking powder biscuit mixes and for that reason, impose the same shortening requirements as previously covered. Other muffin mixes are similar in character to the cake mixes and for that reason, would benefit through the use of shortenings previously described for this purpose.

It is obvious that the type for shortening used in prepared mixes is of crucial importance to final results. The technologists engaged in formulation of the mixes must have comprehensive knowledge of the subject and of its various aspects; namely resistance of the fat to rancidity, crystalline stability of the shortening, emulsification properties of the shortening, lubricating or shortening values of the fat, resistance of the fat to hydrolysis, suitable measurements for plasticity and above all, an understanding of the different requirements necessitated by the multiplicity of differing characteristics desired in the final baked product.

Egg Products

Egg Yolk and Whole Egg.[1]—Egg yolks and whole eggs, although used in relatively small amounts in most baked products and prepared mixes, play a vital role in determining the final quality and cost of the finished product. Eggs are extremely important to bakery production and mix manufacturers because of their functional performance and also because their relative high price has a significant effect on the final cost of the baked product. Fresh or frozen eggs have been used by generations of bakers and housewives, often with little concern or regard for the reasons they are included or the part they are expected to play in the quality of the product. As our modern economy has necessitated a critical look at ingredient costs, and technology has developed products with varying functional performance, the intelligent mix producer is finding it necessary to choose the proper product to carry out each of the various functional roles for which eggs are included. The development of modern egg solids products has increased the opportunity to select and obtain

[1] This section was prepared with the assistance of Dr. R. H. Forsythe.

the best performance at the lowest ingredient and production costs. For the best selection, one must be aware of the basic functions expected of eggs in the many different baked products produced. According to Pyler (1952) there are six functions performed by eggs in cakes and similar products. These are as follows: (1) binding action; (2) leavening action; (3) emulsifying action; (4) flavor; (5) color; and (6) nutritive value.

Whole eggs and yolks with their high protein content are capable of absorbing and binding large quantities of water. Upon binding of the water the proteins become capable of being stretched and extended into a structure within the batter, which when subjected to heat set up into a rigid framework holding large quantities of sugar, fat and flour. Egg proteins, like other proteins, denature when heated, and this characteristic, coupled with the ability to bind water, constitutes two of the major functional roles expected by the mix manufacturer. Many variables encountered in processing affect this binding and stabilizing action among which should be included (1) the amount of heat treatment of the liquid or dry state, (2) length of storage, and (3) the ingredients added prior to drying such as sugars, salt, starches, and chemical additives.

The ability of egg products to incorporate and hold gases is an important function in many or all cakes. In the sponge type cake where the egg may furnish all or most of the leavening action some types of egg solids are not satisfactory. However, as will be pointed out later, egg products dried after the addition of carbohydrates, retain to a major extent the leavening ability of the original fresh egg yolk or whole egg. In these sponge-type cakes the egg serves not only to incorporate air but improves the cell structure and holds the volume of the product after baking, which chemical leavening agents alone will not do. In batter-type cakes where the leavening action is primarily from chemicals, the egg proteins help to retain the gases developed and hold the desirable small cell structure by preventing the coalescence into large air pockets.

Whole egg and egg yolk are in themselves an excellent emulsion, and through the action of the lecithin they contain act as good emulsifying agents in baked products. Thus egg assists in the incorporation of fats into batter cakes and contributes to the tenderness and moistness of the finished product. Some of the emulsifying action may be lost if the eggs are dried under too drastic conditions but recent developments indicate that most of the emulsifying power can be retained.

The flavor of eggs contributes to the organoleptic properties of cakes, resulting in distinctive flavors when used in relative large proportions. The retention of the desirable flavor of fresh eggs during the drying and storage of egg yolk and whole egg has been one of the major drawbacks in

many baking mix applications. Improvements in technology of eggs have resulted in products capable of inclusion in all baking mixes except where very high levels of eggs are employed. The deterioration of the flavor of egg solids is primarily the result of changes in the lipid fractions which, because they are so highly emulsified, offer large surfaces for oxidation and enzymatic action. Probably for this reason, the use of antioxidants has not been very successful in retarding the deterioration of flavor in dried egg products.

The pigment of egg yolk and whole egg is a complex mixture of carotene, xanthophylls, and other carotenoids which is governed almost entirely by the feed consumed by the chicken. In certain applications, egg noodles for example, this is an extremely important function but in most prepared mixes artificial color has been employed because of its relatively low cost. It has been difficult however to duplicate the clean, rich yellow color of the egg carotenoids in yellow and sponge cakes.

The nutritive or "food" value of the egg has been largely overlooked by manufacturers of prepared mixes. In some products the level of egg is quite low and the nutritive values contributed are of little value. It should be pointed out, however, that the inclusion of any quantity of egg improves the nutritive value of the food. Eggs are an excellent source of the most biologically efficient proteins. Egg fats contain large quantities of the unsaturated fatty acids now recognized as essential in human nutrition. Eggs contain significant amounts of all of the known vitamins with the exception of vitamin C, as well as most of the essential minerals.

In addition to the functional characteristics mentioned above, the user of egg products should be concerned about the bacteriological properties. While most prepared mixes are cooked before consumption there are several notable exceptions on the market today. Icings and meringue mixes do not use egg yolk or whole egg but in these instances the bacteriological properties are of the utmost importance. As refrigerated doughs increase in popularity this problem will need to receive further attention. It should be noted that even in those cases where sufficient heat is employed to destroy most pathogenic bacteria, large numbers will still constitute a menace and should be controlled carefully by the manufacturer. Egg products of excellent bacteriological properties are available today but usually demand a slightly higher price because of the extra precautions and manufacturing techniques required.

A wide variety of commercial egg solids products have been developed and are commercially available for specialized application in the prepared baking mix field. In the development of these products primary attention has been paid to the functional and organoleptic roles demanded in the different mixes.

1. **Standard Whole Egg Solids.**—This product is used in cookies, layer cakes, pound cakes and other mixes where the functional role of the egg does not include leavening or foam formation although when properly formulated such applications may be possible. This product is not generally suited for grocery products prepared mixes as it has insufficient shelf life. Widespread use is found in institutional prepared mixes. Three pounds of water and one pound of whole egg solids are used to obtain the liquid equivalent of fresh whole egg.

2. **Stabilized Whole Egg Solids.**—This product is identical to the above mentioned except that the shelf life has been extended by the removal of the residual glucose naturally occurring in the egg. This process permits its use in grocery product mixes and makes cold storage unnecessary for limited periods. (The usual commercial practice is for the egg manufacturer to hold this type of product under cold storage until delivered to the customer.) Many institutional mixes use this product to give added shelf life and eliminate old inventory problems.

3. **Fortified Whole Egg Solids.**—A variety of products are manufactured under this category consisting of mixtures of whole egg and yolk in various proportions. This common proportion is about two-thirds of liquid whole egg and one-third liquid yolk, which when dried results in a product having slightly over half egg yolk solids and slightly less than half whole egg solids. It finds applications in formulations requiring both whole egg and yolk, or egg whites and yolk. Economic considerations often determine the extent to which this product is utilized. At the present time it has found widest use in the baking industry in layer type cakes, cookies, and sweet goods. It presently has found limited use in prepared mixes. The shelf life of the product can be extended by removal of glucose as in **stabilized whole egg.** Depending on the formulation 2 lbs. of water and 1 lb. of this product gives the approximate composition of the liquid mixture.

4. **Whole Egg Solids—Special Blends.**—A number of specialized types of whole egg solids are manufactured which consists of either straight or fortified whole egg and some type of carbohydrate. The most usual of these products is one containing whole egg solids and sucrose (20 to 30 per cent solids basis). The primary purpose of the inclusion of the sucrose or other carbohydrates is to retain the leavening or foaming ability of the egg solids. These products usually go into solution more easily and retain a high degree of the emulsifying ability of the fresh egg. They find application in sponge and other foam type cakes and widespread use in the cookie industry. Their use in grocery products is impractical at the present time due to the instability of the flavor. The reactions between sucrose and the lipid fractions of the egg result in the

development of off-flavor and odors at room temperature. Recently carbohydrates derived from corn products have gained favor by increasing the shelf life. It is expected that these products will be sufficiently improved in the future to warrant their inclusion in both institutional and grocery product prepared mixes.

5. Standard Egg Yolk Solids.—This product is used in layer cakes, doughnut, sweet doughs, and cookies and in most other applications where liquid yolk would be used in baked goods. Egg yolk solids do not retain all of the leavening, foaming or emulsifying ability of fresh or frozen egg yolk and so are not recommended for use in sponge type mixes unless special formulations are employed. Egg yolk solids are used where a rich natural egg color is desired. The most widespread use of egg yolk solids at the present time is in institutional doughnut mixes. One pound of egg yolk and 1.25 pounds of water is equivalent to liquid yolk. It is generally recommended that this product be held under refrigeration.

6. Stabilized Egg Yolk Solids.—Additional shelf life can be obtained by the removal of glucose as is the case with whole eggs. The product can be used for the same applications and is generally used in all grocery product prepared mixes and in some institutional mixes containing larger quantities of egg yolk. It is expected that the use of this product will increase compared to the standard product. Cold storage is recommended for this product only in the warm summer months.

7. Special Egg Solids Products.—A number of commercial products are available, which have been developed through the cooperation of prepared mix manufacturers and egg solids manufacturers to meet special needs and requirements. These include a variety of approved food additives with blends of egg yolk and whole egg. This experience has demonstrated the adaptability of egg products in many special mix formulations.

Egg Albumen.[1]—One of the most important constituents in angel food cake and similar foam type mixes is the albumen. The greatest single reason for albumen (liquid or dried) failing to perform in angel food cakes is yolk contamination.

In simple angel cake formulas (without chemical leavening ingredients), 0.10 to 0.15 per cent whole yolk will impair performance. Even in complex, more tolerant formulas, only slightly higher amounts can be tolerated.

There are two ways yolk gets into albumen. One is through poor processing operations, using yolk-contaminated equipment, or using separating techniques that allow yolk to fall into albumen. The other way is by using shell eggs whose albumen already has yolk in it before it is

[1] This section was prepared with the assistance of Dr. C. F. Smith.

separated. In this case, the yolk has diffused through the yolk membrane into the albumen.

To keep yolk out of albumen during processing, all equipment must be free of yolk—and kept free. Breaking assemblies and equipment which become contaminated should be washed or wiped clean immediately. Cups of albumen into which yolk has fallen should be used for whole egg solids and not included in angel cake albumen. The quality of the shell eggs used is of importance. High quality, fresh shell eggs have very little diffused yolk in the albumens, and they have strong yolk membranes. So there is less chance of yolk breakage and of yolk falling into albumen. An albumen can easily be produced in regular commercial operations which has less than 0.2 per cent yolk in it.

In general, research has shown that the "diffused yolk lipids" do not have the same ratio of fat constituents as whole yolk. Instead of containing the amounts of glyceride, cephalin, lecithin, and cholesterol found in whole yolk, the diffused yolk lipids appear to be almost entirely glycerides.

The singularity of the fat substance of diffused yolk lipids entirely alters the value of a result obtained by the film test method and the way it can be interpreted. If you don't know whether the substance measured is whole yolk or only glycerides, a contamination of 0.03 per cent to 0.04 per cent as determined by the film test method, is the maximum allowable for albumen for angel cakes. That 0.03 per cent to 0.04 per cent might represent only glycerides, and they would have the same detrimental effects as 0.09 per cent to 0.12 per cent whole yolk.

TABLE 70

EFFECT OF ADDITION OF YOLK GLYCERIDES ON ALBUMEN PERFORMANCE

Glycerides Added, Per cent Equivalent of Yolk	Whip Time	Cake Height	Yolk Film Test Results, Per cent
Control	$3\frac{1}{2}$″	108 mm.	0.014
0.025	$3\frac{1}{2}$	110	0.019
0.050	4	103.5	0.025
0.075	4	87	2.028
	$5\frac{1}{2}$	105	
0.10	4	86	0.035
	6	106	
0.125	4	63	0.057
	8	95	
0.150	4	No Foam	0.062
	10	98	

Bergquist and Wells' (1956) film test was set up to measure per cent contamination by whole yolk fat. This means the calculated film area of yolk fat was the monomolecular area of all yolk lipids found in whole

yolk; glycerides, lecithin, cephalin and cholesterol. These fractions were separated and it was discovered that each of these lipids produces a smaller monomolecular film area, the composite of which represents whole yolk fat.

In an experiment to find out which lipids were detrimental to albumen performance, it was found that the glycerides (true fats) were much more detrimental than the others. The effect of adding known amounts of these glycerides on cake volume is shown in Table 70. These data are in agreement with the performance of albumen contaminated with equivalent amounts of whole yolk.

If only yolk glycerides are present, equivalent whole yolk contamination can be calculated approximately and albumen performance predicted by multiplying results 2 to 3 times. For example, if 0.03 per cent yolk is obtained by the film test, equivalent whole yolk would be 0.06 to 0.09 per cent. Likewise, 0.05 per cent would be equivalent to 0.10 to 0.15 per cent.

If the shell egg has not been subjected to high temperatures and rapid evaporation, yolk film probably represents whole yolk. If so, film tests results can be as high as 0.10 per cent and the albumen may perform satisfactorily. If history of the shell egg or frozen egg white is unknown, such as most commercial eggs, or if the shell egg has gone through an initial period of rapid evaporation and if the film test is below 0.03 per cent, the albumen will probably perform satisfactorily (because it is the same as .09 per cent whole yolk). If the film test of such eggs is 0.05 per cent or more, the albumen may not perform satisfactorily. The 0.05 per cent may represent the glycerides (an equivalent of 0.15 per cent whole yolk), which cause the albumen to fail to perform; or it may represent whole yolk and the albumen will perform satisfactorily.

It should be stated here that these data and this hypothesis are based on indirect evidence that the glyceride fraction is the culprit. Research is under way to chemically identify this minute amount of yolk lipid which diffuses into albumen.

In any case, a film test below 0.03 per cent should result in a satisfactorily performing albumen.

Whip boosters, in general, shorten whip time necessary to make cakes, increase tolerance against cake failures, and slightly increase cake volumes. Whip boosters are beneficial only when used with quality albumen and our data indicate that albumen with high amounts of yolk *is not helped, but further impaired*, by the addition of whip boosters. Several additives are now in use. Sodium desoxycholate (trade-named NAD by Kraft Foods) is under patent protection, and has FDA approval.

Data in Table 71 illustrate the advantages offered by the addition of less than .1 per cent of a whip booster. A whip booster cannot upgrade

poor quality albumen, it can only improve good quality albumens. In fact, addition of whip boosters to poor albumen may further impair the performance of the albumen.

Table 71

EFFECT OF SODIUM DESOXYCHOLATE[1] IN DRIED EGG ALBUMEN

Whip Time, Minutes	Cake Height in Mm. Plain Albumen	Albumen with NAD
$1\frac{1}{2}$	106	135
$2\frac{1}{2}$	124	132
$3\frac{1}{2}$	127	134
$4\frac{1}{2}$	122	132
$5\frac{1}{2}$	123	127

[1] Kraft Foods Co. Additive, Pat. Pend.

Milk[1]

The benefits resulting from the use of milk solids in mixes have been recognized by technical and practical people. The introduction of commercial drying equipment, along with various skills in the dairy industry, has resulted in the production of products of good quality which will perform consistently from day to day in large scale operations. Converting fluid milk into powder has provided a source of milk which can be stored and handled in an operation with the same general care as is used in the handling and storage of flour.

Nonfat milk solids can be of two general types, namely roller process and spray process powder. In recent years, the popularity of the spray product has increased tremendously at the expense of the roller product, for reasons of the economics in the dairy industry and because of the greater uniformity of product generally achieved in a spray process operation.

Nonfat dry milk, however, is not adequate for mix operation unless it is properly processed. Technologists have learned that only milk solids manufactured with proper equipment and with proper heat treatment will perform satisfactorily. Milk solids contain a relatively high percentage of protein (approximately 36 per cent). The larger portion of these proteins is casein. Another rather minor portion, the whey proteins, can cause some rather drastic chemical changes when milk is added to bread mixes if this milk has not been properly processed. The denaturation or chemical inactivation of whey proteins is a fundamental requirement in processing milk for a bread mix. A test has been developed (the Harland Ashworth whey protein nitrogen test) for the determination of the de-

[1] This section was prepared with the assistance of Mr. Ray Mykleby.

gree of denaturation of these whey proteins. This test is, in fact, used rather universally by the large processors of nonfat dry milk. Many correlation studies have been performed confirming the relationship between whey protein nitrogen content and baking behavior of nonfat dry milk.

There are approximately 7 mg. of whey protein per gm. of nonfat milk solids. High heat treatments or high denaturation which produces nonfat milk solids suitable for bread mixes will have about $1^1/_2$ mg. of whey proteins undenatured. In other words, approximately 78.6 per cent of the whey proteins have been denatured. Low heat treatment will have in the neighborhood of 6 mg. of whey protein undenatured, or approximately 21.5 per cent of the whey proteins being denatured. In cake mixes there is a difference of opinion as to whether the low or the high protein denaturation is desirable. In doughnut mixes the majority of opinions seemed to favor a high denaturation of whey protein.

The specific water absorption characteristics of milk powders is another factor of concern to many people in the baking and general food processing industry. Certain process conditions during manufacture will result in milk powders having varying degrees of water absorbing or water-holding capacity. This characteristic is fundamentally associated with the casein complex in the milk solids, and is of concern where specific water retention, specific viscosities and the economics of these processes are involved. High casein denaturation will give high water absorption. As a general statement relatively complete denaturation of whey protein, plus relatively high water absorption characteristics, is desirable in powder to be used for a yeast raised dough type of mix.

There are a number of specific tests which can be used for measuring water absorption characteristics in milk solids. The Hoffman-Dalby farinograph procedure measures this absorption characteristic of milk in combination with flour. The Brookfield viscosimeter can be used for measuring viscosities of milk and water suspension. Other more simple dough tests can be made for rough estimations of water absorbing characteristics.

There are certain types of products made from mixes that may advantageously use a low heat type of nonfat dry milk. This type of milk is processed under conditions of minimum heat treatment and results in powders having very limited denaturation of the whey proteins, with low relative viscosities and generally less cooked or heated flavors than are found in the previously mentioned high heat types of product. Such powders may perform advantageously in certain fillings, toppings, creams, etc.

The bacteriological characteristics of nonfat dry milk are receiving considerably more attention during recent years. It is possible to secure

powders, for example, where bacterial populations have been reduced to conditions of near sterility. These are characteristics that are of concern to people interested in the refrigerated type of biscuits and products of this nature.

In recent years instant dry milks have found a definite place on the shopping list of the American housewife. These instant nonfat dry milks can be produced by a variety of processes which change their physical characteristics to the extent that they are easily dispersed in water. This type of nonfat dry milk may be of commercial significance in certain mixes where this particular characteristic would be advantageous. As a general rule, however, the increased costs involved in instantizing powders make them prohibitive in most large-scale commercial operations.

A relatively new product, edible sodium caseinate has been introduced recently. This is a dry powder of approximately 90 per cent protein content with a full complement of amino acids, particularly lysine, making it attractive to people interested in specialty types of high protein mixes.

This discussion has attempted to summarize some of the general types of dried milk products available to the food processing industry. There are others, and, in fact, variations of these that may be more advantageous to certain specific industrial users. Most large dairy processing concerns are willing and anxious to cooperate with industrial users in attempting to produce products which will perform to advantage in their specific manufacturing operation.

Sugars[1]

Sugars are an exceedingly important ingredient in mixes. The functions that sugars play in mixes are: (1) improve flavor; (2) add richness; (3) impart keeping quality; (4) act as a tenderizing agent; (5) contribute to grain and texture; and (6) affect color of crust.

Sugars vary in their relative sweetness, as shown below:

Relative Sweetness Rating

Kind of Sugar	*Relative Sweetness*
Sucrose (cane or beet sugar)	100
Levulose, fructose	175
Invert sugar	130
Dextrose hydrate	70
Corn syrup (enzyme)	60
Corn syrup (acid)	30
Maltose	30
Lactose	15

[1] Data for this section were supplied by the California and Hawaiian Sugar Company.

The most important sugar used is sucrose (cane or beet sugar). This varies in granulation. Types that are of interest to mix manufacturers include sanding sugar, granulated sugar, bakers' special, powdered, drivert, and fondant and icing sugar. Below is a typical screen analysis of sanding sugar. This can be packed in a separate package and used to sprinkle on top of products baked from mixes, imparting a sparkle to the finished product.

Typical Screen Analysis of Confectioners Sanding Sugar

Per cent on 20 mesh	9.3
Per cent on 28 mesh	49.2
Per cent on 35 mesh	37.6
Per cent through 35 mesh	3.9

Regular granulated sugar is frequently used in mixes. A typical screen analysis of this product is given below:

Typical Screen Analysis of Granulated Sugar

Per cent on 28 mesh	0.4
Per cent on 35 mesh	13.8
Per cent on 48 mesh	40.2
Per cent on 80 mesh	40.6
Per cent through 80 mesh	5.0

Bakers' special sugar is considerably finer than granulated sugar, as shown by the screen analysis. This produces a very fine texture and grain.

Typical Screen Analysis of Bakers' Special

Per cent on 28 mesh	Trace
Per cent on 35 mesh	0.4
Per cent on 48 mesh	1.7
Per cent on 80 mesh	24.8
Per cent on 100 mesh	32.3
Per cent on 150 mesh	31.6
Per cent through 150 mesh	9.2

Powdered sugar has a screen analysis as shown below.

Typical Screen Analysis of Powdered Sugar

Per cent on 100 mesh	0.3
Per cent on 150 mesh	1.8
Per cent on 200 mesh	6.6
Per cent on 270 mesh	8.2
Per cent on 325 mesh	10.2
Per cent through 325 mesh	72.3

Powdered sugar is mixed with very low moisture food grade starch to retard caking. It is frequently used in mixes, and imparts easy spreading qualities to certain icings which are packaged and sold with cake mixes.

"Drivert" sugar is a trade name for a special sugar manufactured by the California and Hawaiian Sugar Refining Corporation. The significant thing concerning this sugar is that it is 10 per cent invert and 90 per cent fondant and icing sugar. This combination acts as a moisture retaining agent in products baked from mixes. It is frequently used in preparing fondant or icings.

Fondant and icing sugar particles are between 10 to 20 microns in diameter, and are about one-hundredth the size of powdered sugar particles. The size of the particles are of particular significance in preparing icings which resemble a cooked icing. When tasted, the particles cannot be detected.

Glabau (1952) has conducted extensive baking tests on cakes with liquid and cane sugar of varying degrees of granulation. He has come to the conclusion that the particle size of the sugar is reflected in the specific gravity of the batter.

There is a tendency for the batter to offer greater resistance as the particle size of the sugar is increased. From a practical standpoint, the cakes baked from the various granulations were all equally good with respect to cake scores. It may be said that in general any granulation of sugar can be successfully used and that the difference between the cakes made from the various granulations is small.

In the production of cookie mix, the different granulations show very wide variations in the baked cookies. It is generally stated that as the particle size of the sugar is increased, the spread of the cookie becomes greater. If one desires to produce a very thick cookie, powdered sugar would be the appropriate type to use.

Brown sugars are used by mix manufacturers, although they are extremely difficult to incorporate as an ingredient due to their caking quality. These sugars should be stored at a relative humidity of 50 per cent or over. They are used for the flavor and color that they impart to prepared mixes. The chemical composition of brown sugar is shown on page 366.

Dextrose or corn sugar is frequently used as an ingredient in mixes, the most common one being pancake mixes. The reason for its use is that it browns more quickly than cane sugar. There are two forms of dextrose, dextrose hydrate which contains approximately 8 per cent moisture, and anhydrous dextrose containing only 0.2 per cent moisture. The anhydrous type can be used in mixes when it is desired to lower the

Chemical Composition

	Golden C Per cent	Yellow D Per cent
Sucrose	86.0	85.4
Moisture	3.9	3.7
Invert sugar	5.4	5.5
Ash (mineral matter)	2.4	2.9
Organic non-sugars (by difference)	2.3	2.5
	100.0	100.0

moisture in the total mix. It takes water from the other constituents of the mix and reverts to the hydrate.

Corn syrups are not generally used in prepared mixes because of the difficulty of incorporation. However, certain dried corn syrups can be used in very small amounts, particularly in icings.

Malt syrup cannot be used to any great extent because of the difficulty of incorporation. Dried malt has been used in a very small percentage. Dried malt is extremely hygroscopic, which limits its use. Fromalt recently developed by the Froedert Malt Corporation is a caramelized malted barley flour and can be used to impart flavor to mixes.

Molasses is generally used in the production of gingerbread mixes. The patent for the incorporation of molasses in gingerbread mix was taken out by Duff and Dietrich (1933). Another patent for incorporation of molasses in gingerbread was assigned to General Mills in 1950 (Sald and Huber 1950). Both of these two methods are being successfully used today. A patent entitled "Apparatus for Drying Molasses" is assigned to Food Concentrates, Inc. This type of dried molasses is currently being used for some mixes.

Honey has been dried, but it is so hygroscopic that the dried form cannot be used in the production of mixes.

Another interesting sugar is found in the form of dried whey which is 72–73 per cent lactose. Whey has a very pronounced browning effect and tenderizing effect in cakes. Glabau (1955), commenting on the use of whey in cakes and cookies, has the following to say:

"1) The spray type of whey used in this study improves the structure of the sugar cookie.
2) The most pronounced physical property is in the color or caramelization of the cookie during baking.
3) The difference in the tenderness of the cookies is indicated to some degree in the breaking point. One can readily detect the difference between the cookie with the low whey value and that with the higher value."

The increased caramelization as compared with cane sugar is undoubtedly due to the sugar protein reaction. The same sugar protein reaction holds true when dextrose is used in mixes. Sugar in its modified form is used in the production of caramel, which in turn is used as a constituent of caramel cake mixes.

Maple sugar is used to a very limited extent, due to its high cost and the uncertainty of a uniform supply.

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John T. Goodwin

Wet-Milling

INTRODUCTION

The corn wet-milling industry can be traced back to 1842 when Thomas Kingsford, who was working in the wheat starch plant of William Colgate and Company in Jersey City, New Jersey, produced the first commercial starch from corn. Kingsford's process, which involved soaking the kernel in water and extracting the starch, used the same basic principles that are still in effect in present milling practices. Of course, many technological improvements have since been made.

A few years later, three corn starch plants were erected, notable among them being the Kingsford plant at Oswego, New York and the Duryea plant at Glen Cove, Long Island.

A booklet by Jeffries (1942) contains much information about the operations of the Duryea plant. It was entirely self-contained and made all its own equipment, boxes, and wooden tanks. It had a press for printing its labels and manufactured its own illuminating gas. There was not an electric motor or electric light in the plant in 1891.

The corn was placed in wooden, flat-bottomed tanks, covered with warm water and allowed to stand. After the corn was sufficiently softened, it was ground in stone mills and sieved and washed on silk screened shakers powered by reciprocating engines. The slurry that was washed through the sieves was put in wooden tubs, treated with caustic soda and allowed to settle. After settling, the water was sent to the sewer, taking all of the gluten and soluble materials with it. This settling process was repeated three times for each batch.

Yield calculations were not made in those days, but it seems probable that the starch recovery could not have been much above 50 per cent of the total starch available. No chemical tests were run in the plant, but an effort was made to control the alkalinity of the settling tanks. Key employees were trained in testing the slurry in the settlers and they either approved the batch or caused more caustic soda to be added. When the starch was hydrolyzed to convert it to "glucose," tasters who had no other responsibility, judged the completeness of the conversion.

From these crude beginnings, have come the modern efficient corn refining plants. They do not empty their valuable products down the drain,

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they have excellent control laboratories, and they use the most modern equipment available to produce quality materials economically and maintain good material balances.

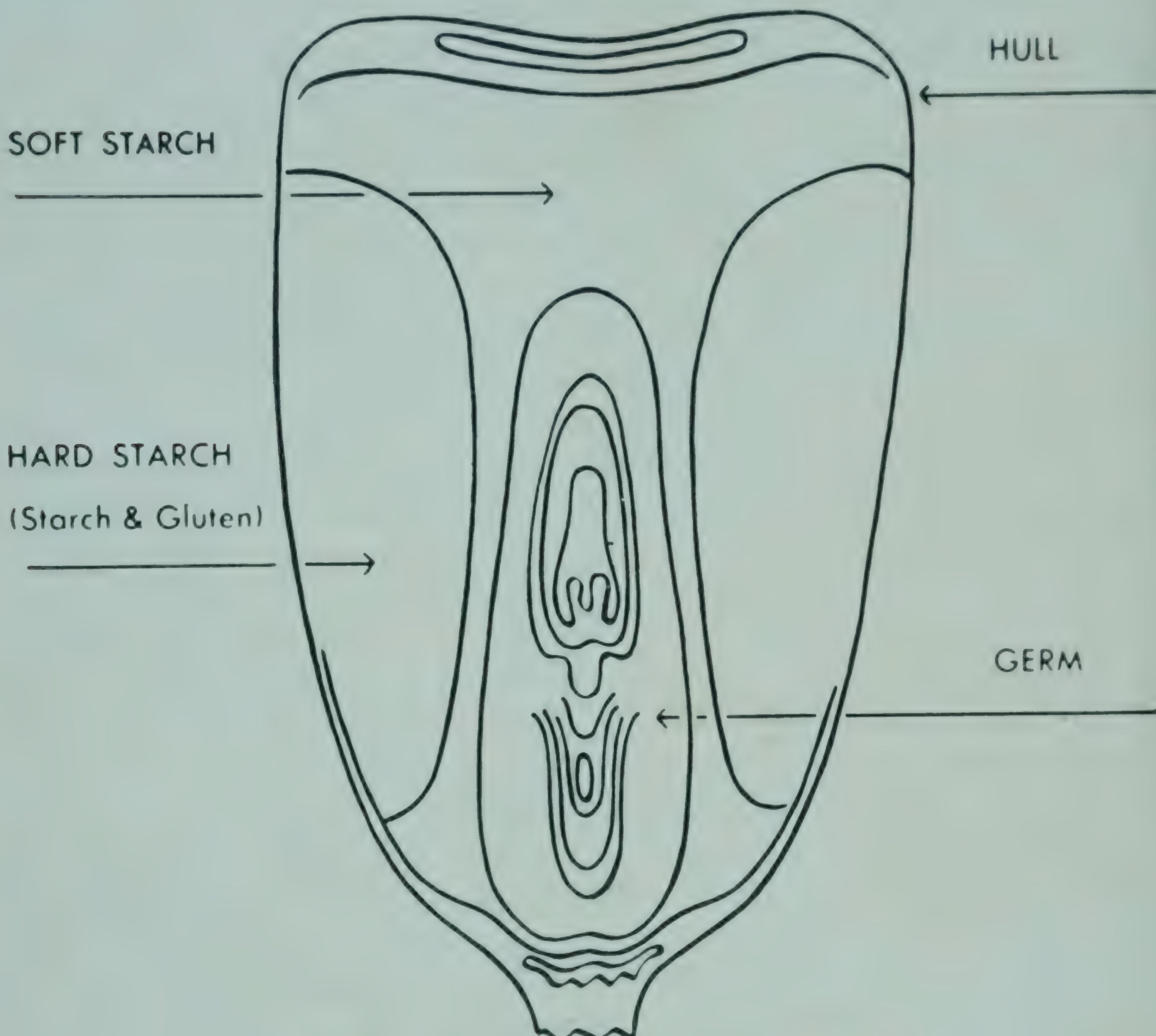


FIG. 86. DIAGRAM OF THE CORN KERNEL

THE CORN KERNEL

The composition of the corn kernel on a *dry* basis is shown in Table 72. These figures are subject to slight variations depending on weather conditions, type of seed and soil, amount and type of fertilizer and other factors, but represent good averages for yellow dent corn. The water content of the corn which comes into the wet-milling plants varies from 10 to 25 per cent.

THE WET-MILLING PROCESS

Raw Material

The corn wet-millers use only shelled corn. These kernels are shipped into the plants at a typical rate of about 260 carloads per day. The corn

is transferred from boxcars to cleaners and then to temporary storage bins to await further handling.

Th· cleaning operations involve passing the corn past powerful magnets

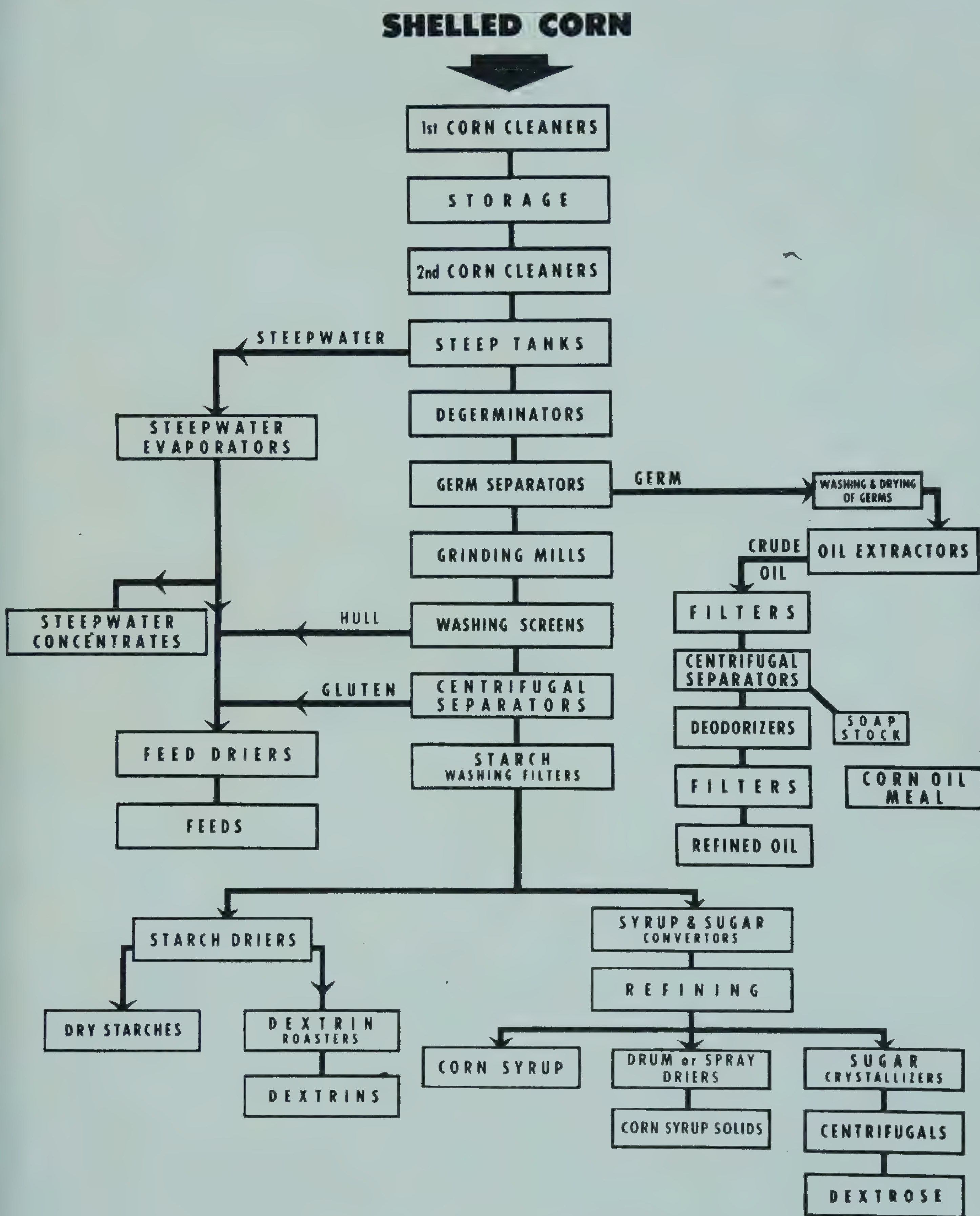


Fig. 87. Flow Diagram of the Wet-Milling Process

which remove scrap iron, steel, or nails which may have been introduced in the corn by previous handling. After passing the magnets, the corn is weighed on scale hoppers and sampled for quality.

TABLE 72

COMPOSITION OF THE CORN KERNEL

	Per cent
Starch	73
Sugars	3
Pentosans	4
Protein	10
Oil	4.5
Fiber	3.5
Minerals	2

After sampling and weighing, the corn is further cleaned by passing over perforated screens. The upper screen has holes just large enough to let corn and smaller particles through and the lower screen holds back the corn but lets smaller pieces of chipped corn, cobs, sticks, and stones through. Next the corn is blown with high-pressure air. This removes low density materials and dust which are delivered to cyclone dust collectors. Because the corn itself is considerably agitated by the air, a further separation of higher density materials occurs and these materials are removed from the bottom of the flowing stream of corn.

Steeping

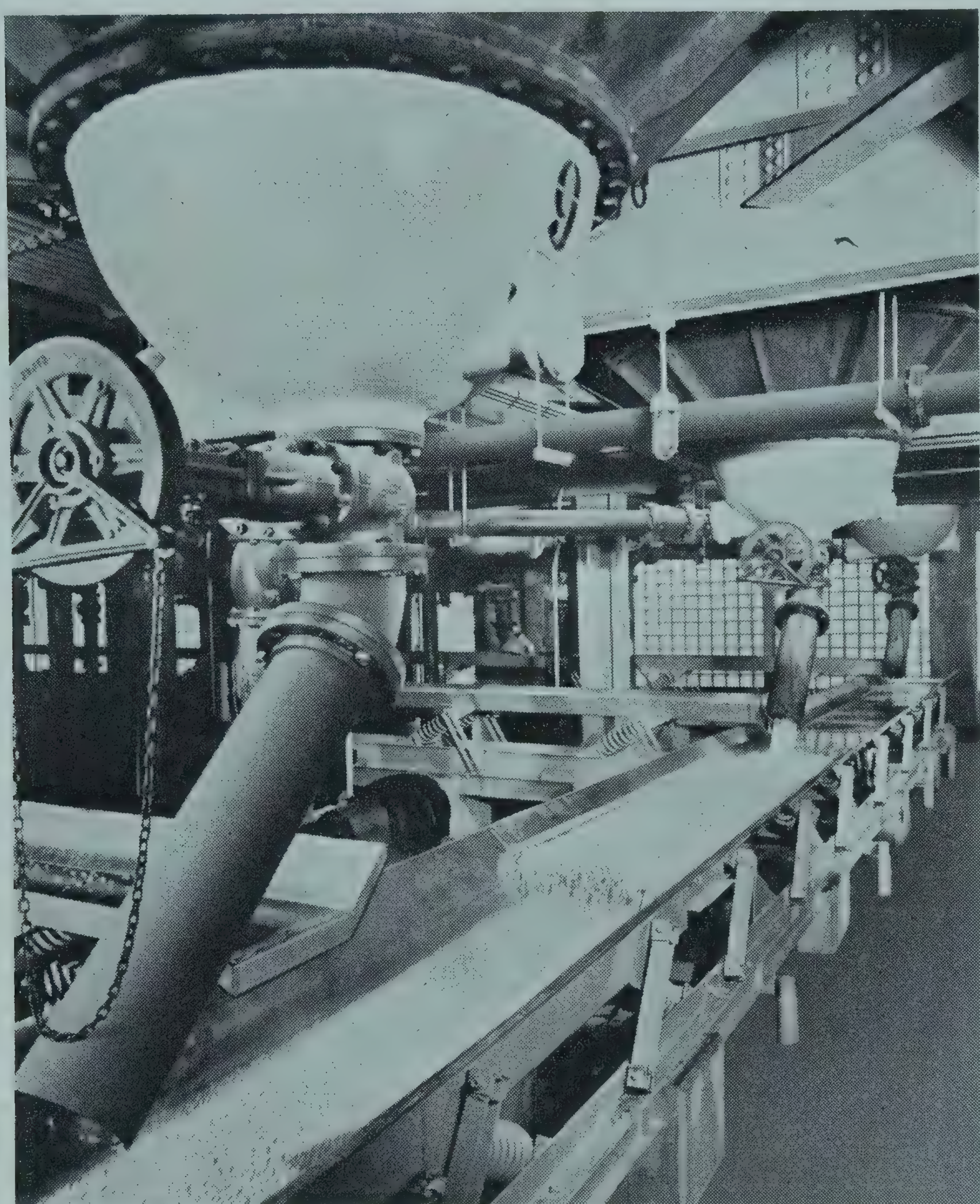
Cleaned corn is transferred to "steep" tanks which hold 2,000 to 3,000 bushels. The purpose of the steeping operation is to soften the kernels so that the subsequent milling operations and separations can be carried out efficiently. Warm water containing a small amount of sulfur dioxide is circulated through the steep tanks. The sulfur dioxide is used for two principal reasons; first, it prevents undesirable fermentations and second, it helps soften the kernel. The corn refiners manufacture their own sulfur dioxide by burning sulfur in rotary burners.

In the early days of the wet-milling of corn, batch methods were used in steeping. In other parts of the processing, water was discarded. The result was a large requirement for water and a sizable loss of product in the water which was discharged from the plant.

There were several reasons why corn wet-millers, through the years, had been concerned with the waste water problem. For one thing, the wastes produced pollution and odor problems. Secondly, the manufacturers realized that part of their raw material was being lost. Finally, the water requirements were very large.

In the period 1925 to 1937 several inventors obtained patents dealing with the "bottling up" or "corking up" of the corn refining process. Among those issued such patents were: Jeffries, (1930 and 1937); McCoy, (1931); Moffett, (1928); Sherman, (1925); and Widmer (1926).

This process as it is now practiced, employs water flowing through the steep tanks in such a manner that the freshest water passes over the corn which has been steeped the longest. This procedure insures removal of the maximum amount of soluble material. In addition, water which has



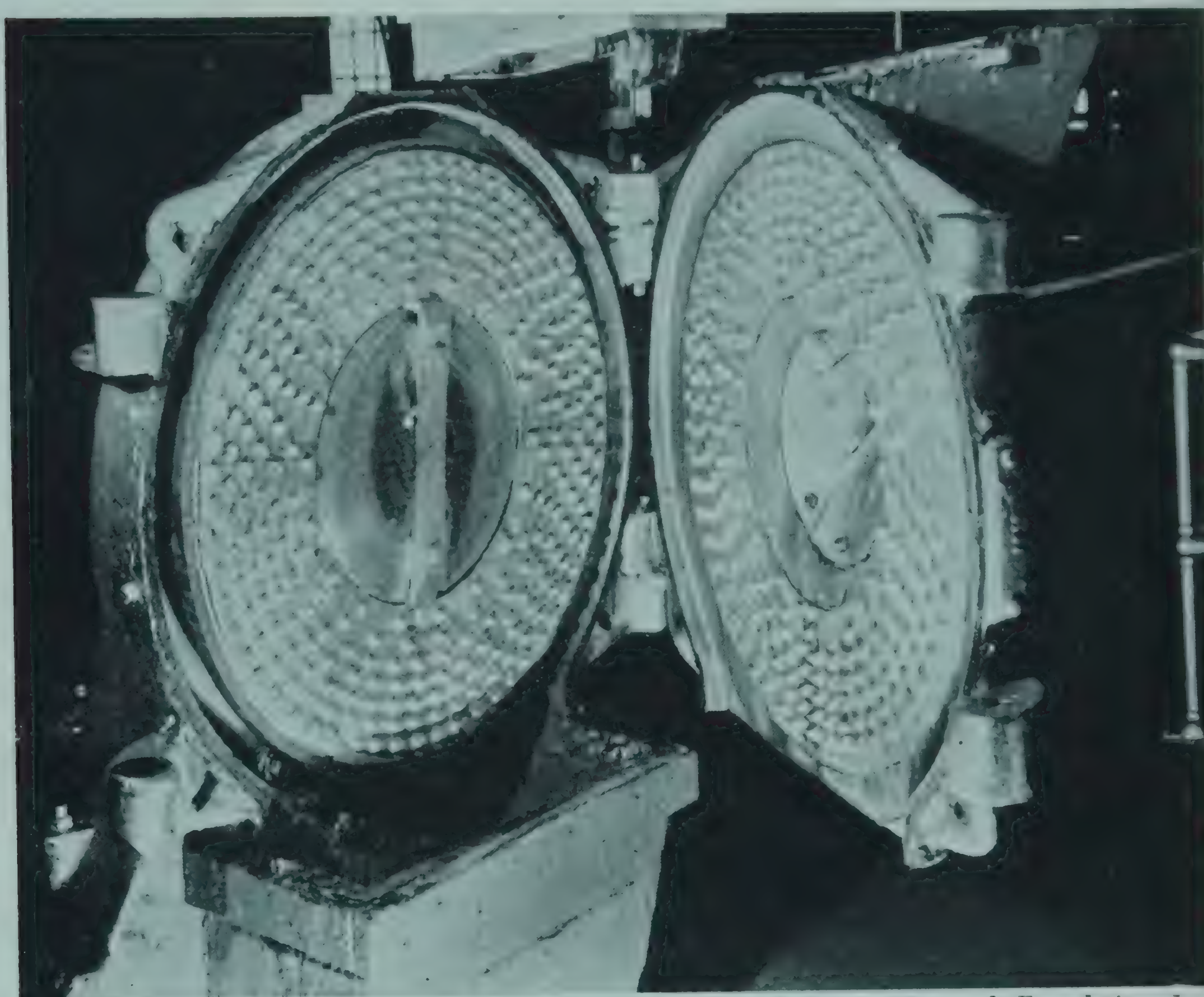
Courtesy of Corn Industries Research Foundation, Inc.

FIG. 88. CORN IS BEING DROPPED OUT OF ONE OF THE STEEPING TANKS

It has been softened by soaking or "steeping," and carried by a vibrating type conveyor to the grinding department.

been used in some other parts of the refining process is added back to the circulating steepwater. These changes increased the yield from 90 per cent to almost 100 per cent, greatly improved the efficiency of the entire process, reduced the waste disposal problems, saved water, and thus lowered costs.

The steepwater is circulated until it contains 6 to 10 per cent solid material. This "spent" steepwater is then withdrawn, concentrated and used for purposes which will be discussed later.



Courtesy of Corn Industries Research Foundation, Inc.

FIG. 89. OPEN VIEW OF A DEGERMINATING MILL

Degermination

The corn which has been softened by the steeping process is now ready for the first milling operation. This step is degermination in which the oil-rich germ is separated from the starch, gluten, hulls, and fiber.

The softened corn is passed over shakers in a second cleaning operation which removes any foreign material which has escaped the first series of cleaning operations or has been picked up in subsequent handling.

The corn is then ground in attrition mills. These attrition mills consist of two plates with projecting teeth. Some models have the two plates rotating in opposite directions and some have one stationary plate and one rotating plate. The plates are so spaced and operated that the corn is torn so as to separate the rubbery germ from the rest of the kernel but to leave the germ intact.

Germ Separation

Either fresh water or water which contains a small quantity of soluble material from some of the processing steps is added to the corn in the degerminating mills. The material leaving the mills is a mixture of water, starch, gluten, germ, and hulls. This mixture is transferred to a series of long troughs which serve to separate the lighter oil-bearing germs from the rest of the material. There is an agitator in the lower part of the troughs which keeps the products mixed and helps free any germs which have been entrapped.

The germs are removed from the top of the tanks along with some of the slurry. The germ-slurry mixture is then transferred to reels or shakers where the slurry is washed off and returned to the starch-gluten stream.

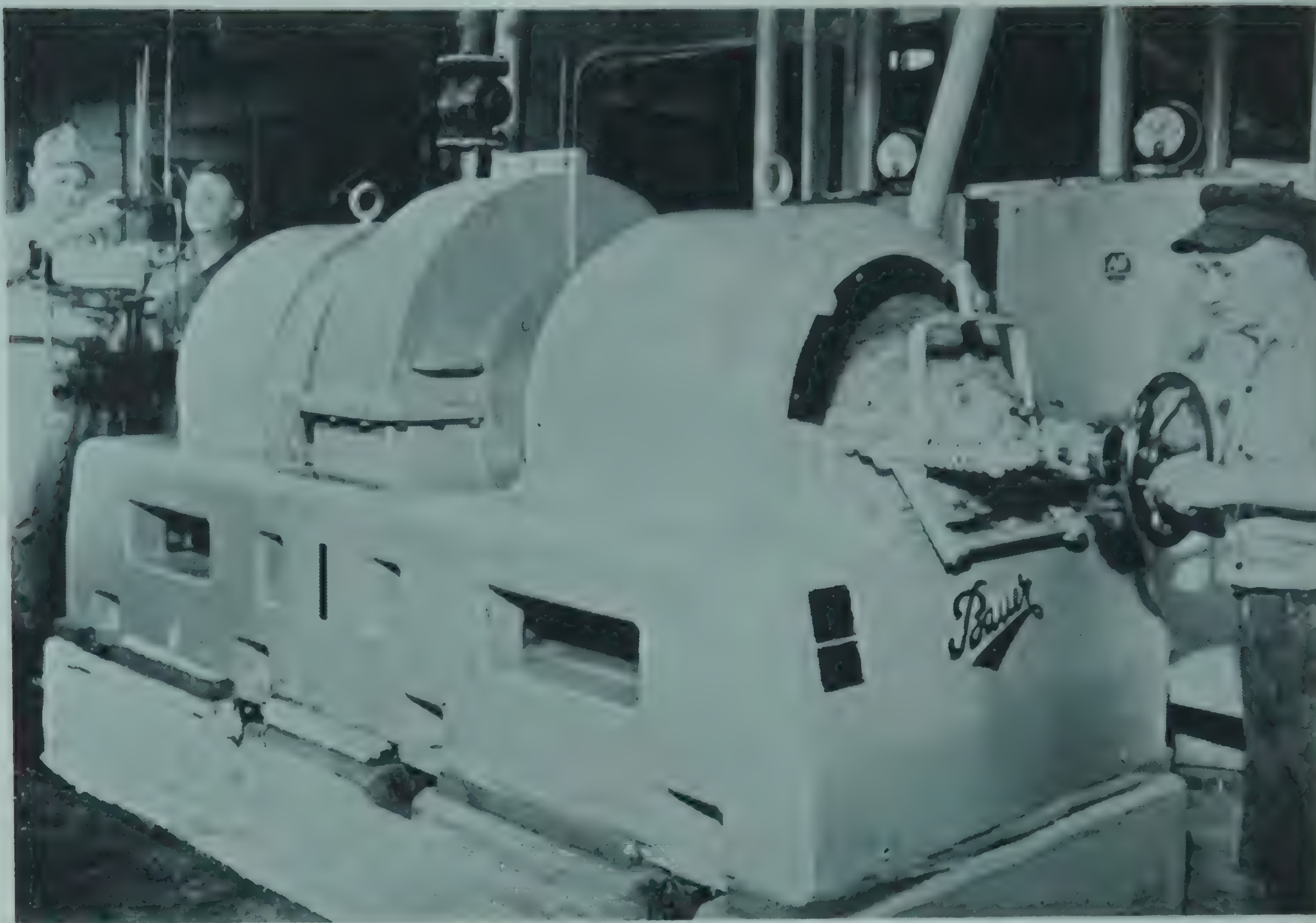
At the same time that the germ is leaving the top of the tank, the mixture of starch, gluten, hulls, and fiber is leaving at the bottom and is sent to reels and shakers where most of the water and soluble materials are removed. Quality control tests are run to insure that the germ has been completely separated from the starch and gluten, and if not, the degermination process is repeated on the solids remaining after the starch-gluten slurry has been removed and passed over the reels and shakers.

The germs are dried and sent to the oil extraction and refining plant. Since this process will be completely described in another chapter in this book, it will not be discussed further here.

Separation of Hulls and Fiber from Starch and Gluten

The wet mash of fiber, hulls, gluten, and starch, which remains on the reels and shakers, is fed to mills which grind the materials to a very small particle size. The hulls and fibers are not reduced in size as much as the starch and gluten in the milling process.

The industry used hard, roughened flat mill stones for many years. These buhr mills were circular and rotated at high speeds over stationary stones. This process reduced the charge to a fine slurry. In recent years the buhr mills have been replaced by stainless-steel vertical mills which do the same job, require less maintenance, and last longer (Fig. 90). The finely ground slurry is transferred from the mills to another set of reels which remove the hull and fiber particles surviving the milling process. These reels are rotating hexagonal screens of copper or nylon and the charge from the mills is constantly fed to them. The starch and gluten are washed through the screens leaving the coarse particles behind. The starch-gluten slurry is then dropped to shakers, which are rectangular screens of nylon of finer gauge than that used in the reels. The shakers vibrate horizontally and remove the last particles of hulls or fibers.



Courtesy of Corn Industries Research Foundation, Inc.

Fig. 90. Bauer Attrition Mill for Fine Grinding of Corn

One of these mills will do the work of several of the older type buhr mills and do it much more efficiently.

Gluten-Starch Separation

The corn refining industry has used gravitational methods for separating starch and gluten since its inception. The old tubs which were described in the introduction were later replaced by starch "tables." This represented a major process improvement.

The starch tables were about 2 feet wide and 100 feet long. They had a pitch of about 5 inches which caused the slurry to flow slowly down them. The tables were almost always wooden although other materials such as concrete and slate have been used. For each 1,000 bushels of corn that were ground, about 3,000 square feet of table area were required. Since many plants mill upwards of 50,000 bushels per day, the floor space requirements for tabling starch were enormous. In fact, the table house was usually the largest building in the refinery.

The starch gluten slurry flowed slowly down the tables and sedimentation occurred with the heavier starch depositing on the bottom and the gluten being removed at the top of the lower end of the tables. The first tabling operation produced starch containing small percentages of gluten and gluten containing larger percentages of starch. Further purifi-

Courtesy of Corn Industries Research Foundation, Inc.

FIG. 91. INTERNAL VIEW OF PRIMARY SEPARATION CENTRIFUGALS

In these machines gluten is removed from starch by centrifugal action.

cation of the starch was accomplished by repeating the tabling operation or by washing the starch on rotary vacuum filters.

The description of the tabling operation has been given because it played a major part in improving the yield of products and lowering their cost. Today the tables have disappeared. Large, highly efficient continuous centrifuges now take the starch-gluten slurry, handle large volumes of material and produce products of high purity (Fig. 91). The tremendous floor space requirements of the table houses are now gone. The entire operation is now enclosed and a major source of air contamination in the plant has been eliminated.

The wet starch is filtered on rotary vacuum filters, washed and dried.

The final product contains only about 0.25 per cent protein and the variation in its composition is extremely small.

The gluten is either separated by sedimentation in large tanks or more generally, is "dewatered" and "destarched" in another centrifuge, filtered and dried. It then is ready to be used as corn gluten meal or corn gluten feed or processed to recover the protein, zein, which has many non-feed uses.

STARCH CONVERSION

Acid Hydrolysis

About half of the cornstarch that is produced is further processed to make corn sugars and syrups. This process, called "conversion" by the industry, involves catalytic hydrolysis of the starch. In the conversion process as well as in dextrinization, starch modification and starch derivatization, the nature of the manufacturing operation undergoes a pronounced change. The milling process is entirely mechanical in nature and resembles other milling operations. It differs from most of the others mainly in the large amounts of water which are used. Conversion and the other processes mentioned above are largely chemical in nature.

Starch is made up of amylose, a linear fraction, which in turn is comprised of many dextrose molecules linked chemically in the 1-4 position and amylopectin, a branched molecule, in which branching occurs at the 1-6 position. There is about one branch per 25 to 30 dextrose units in amylopectin. Since the ratio of amylopectin to amylose in cornstarch is roughly 3:1, there is about one 1-6 linkage, for every 30 to 40 of the 1-4 linkages. Recently, Wolfrom and Thompson (1956) report finding very small amounts of di- and trisaccharides containing the 1-3 linkage.

There is an excellent discussion of the theoretical and experimental work which has been done in an attempt to clarify the mechanism of the acid hydrolysis of starch in the book by Kerr (1950). A great deal of speculation and hypothesizing has been done as to whether the two principal types of linkages have different rates of hydrolysis. The observed results lead to the conclusion that, from the practical standpoint, the rates are not sufficiently different to affect significantly the nature of the products formed. In enzymatic hydrolysis, which will be discussed later, a different set of conditions prevails.

When starch is hydrolyzed with water and an appropriate catalyst, the elements of water are added to the starch molecules. This means that a given amount of starch will produce more than that amount of hydrolytic

products. The extreme case is the conversion of starch to the ultimate product, dextrose. The relationship is shown in the equation below:

$$\underset{\text{starch}}{(C_6H_{10}O_5)_n} + nH_2O = \underset{\text{dextrose}}{n\ (C_6H_{12}O_6)}$$

In this case, 162 units of starch react with 18 units of water to produce 180 units of dextrose. Lesser degrees of hydrolysis, which produce maltose and other polysaccharides, result in smaller weight gains.

The rate of hydrolysis of starch is increased by raising the temperature and by increasing the acid concentration. Because dextrose may react under these conditions to produce a disaccharide according to the equation,

$$2\ C_6H_{12}O_6 \rightleftharpoons C_{12}H_{22}O_{11} + H_2O$$

and because this is an equilibrium reaction, the overall rate of hydrolysis if measured by dextrose produced in a given time, appears to be slower at higher starch concentrations.

The reaction indicated by the equation above as well as the Maillard browning reaction and oxidation which results in the production of furfural-type products are all undesirable. These reactions all lead to decreased yields of desirable products and to the production of materials which have a deleterious effect on the flavor and color of the products. For these reasons, the hydrolysis conditions are usually chosen and controlled to minimize the undesirable side reactions.

The commercial hydrolysis of starch is carried out in such a way that two main classes of materials are obtained; the first class includes the more completely hydrolyzed products which are crystallizable. These are the corn sugars, mainly dextrose and low molecular weight polysaccharides, and highly purified, crystalline dextrose. The other type of material is the non-crystallizable group of products made up of corn syrups and maltodextrines. These products contain dextrose, maltose and other polysaccharides. Whistler and Hickson (1955) have published data on the chromatographic separation and identification of the carbohydrate components in corn syrup. These data indicate that the further the hydrolysis is carried to completion, the more nearly the products approach dextrose in composition. It is interesting to observe that the dextrose and maltose components increase at the expense of the higher polysaccharides while the amounts of the carbohydrates containing from 3 to 9 dextrose units remain relatively constant. These data are shown in Table 73.

The hydrolysis proceeds slowly at temperatures below 212°F. For this reason, starch hydrolysis is carried out in pressure vessels so that higher

TABLE 73

DETERMINATION OF COMPONENTS IN CORN SYRUP

Syrup	Dry Solids[1] Per cent	Syrup D.E.[2]	Saccharides								
			Mono[3]	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona
1	94.10	18.0	5.1	4.8	1.1	4.8	1.2	5.1	5.0	4.1	3.6
2	83.92	26.3	8.3	7.8	1.0	6.2	1.1	7.0	6.3	5.9	5.2
3	79.00	32.6	11.4	9.2	1.3	10.5	1.3	8.6	7.8	5.8	5.1
4	81.80	43.3	19.4	14.4	1.1	10.6	1.2	9.7	8.6	6.2	5.1
5	81.7	49.7	26.1	15.1	2.9	11.2	2.3	9.4	8.4	...	...
6	82.50	55.6	30.9	15.2	3.5	10.0	3.5	9.4	7.2	7.0	5.0
7	82.60	59.9	34.6	15.6	3.7	10.6	3.2	8.7	6.4	...	...
8	70.29	63.0	38.9	22.0	3.8	9.4	3.4	8.2	5.5	3.7	2.4

[1] Dry solids determined by Filtercel method (Cleland and Fetzer, 1941).
[2] D.E. determined by modified Lane-Eynon method.
[3] Glucose values A corroborated by glucose dehydrogenase and Sichert-Bleyer determination.

temperatures may be maintained. These vessels hold a charge of between 3,000 and 4,000 gallons of starch suspension. Typical operating conditions for syrup and sugar manufacture are given in Table 74.

TABLE 74
STARCH HYDROLYSIS CONDITIONS

	Syrup	Sugar
Starch, lbs.	14,480	5,270
Water, gal.	2,340	2,930
Hydrochloric acid, 20 Be.	50	90
Steam pressure, lbs./in.^{2}	30	45
Conversion time, min.	30	40
Temperature, °F.	284	302

The progress of the hydrolysis may be followed by measuring the dextrose equivalent (D.E.) of the solution. This dextrose equivalent is a measure of the reducing sugars present expressed as dextrose. Since the technique for measuring reducing sugars is slow, a derived relationship between dextrose equivalent and specific rotation is used. The specific rotation starts at +200 degrees and gradually decreases during the course of the hydrolysis. Pure dextrose has a specific rotation of +52.5 degrees and the solution approaches this value as a limit. When the specific rotation reaches the desired value, the acid is neutralized with soda ash and the hydrolysis stops.

The neutralized syrup or sugar solution is filtered, passed over a charcoal adsorbent or an ion-exchange resin to remove color bodies and other impurities, and concentrated to the desired solids value by evaporators.

The continuous hydrolysis of starch has been the object of much study and interest to the industry. Patents have been issued dealing with this subject to Sipyaguin and Shoemakher (1943) and Horesi (1944), and Dloughy and Kott (1948) have reported the details of a continuous process for the manufacture of dextrose. However, most of the materials prepared today are being produced by a batch-continuous process.

Enzyme Hydrolysis

It was mentioned earlier that at high starch and high acid concentrations, hydrolysis results in the occurrence of undesirable secondary reactions. The products from the reactions have an adverse effect on the use of such materials in many food applications. These effects are particularly important in the more highly converted materials.

Dale and Langlois (1940) have patented a process which overcomes most of the problems. In this process, an acid hydrolysis is carried out until the desired dextrose equivalent has been reached. The acid is then

neutralized, the syrup is filtered and concentrated. An enzyme is added and the syrup is further hydrolyzed. This type of process produces syrups which are less viscous and more sweet than the acid-converted products. In addition, the secondary reactions are reduced to a minimum and the off-taste products are eliminated.

Dextrose

Dextrose, the end product of starch hydrolysis, is given a special place in this discussion because of its large usage. Of all the corn sweeteners produced, including corn syrups, crude corn sugar and dextrose, the latter amounts to approximately one-third of the total.

The manufacturing information given above indicates that, when it is desired to produce sugars by the hydrolysis of starch, lower concentrations of starch in the slurry should be used. It is also customary to use slightly higher acid concentrations and higher temperatures for longer times. The secondary reactions are not so important because the dextrose is finally purified by crystallization and the undesirable flavor and color constituents end up in the mother liquor.

Newkirk (1936) in a series of publications and patents has described the manufacture and problems involved in the purification of dextrose. The procedure involves introducing a solution of the starch hydrolyzate, which has been concentrated by evaporation, into large vessels which are equipped with agitators. The solution is "seeded" with dextrose crystals and held at a temperature just above ambient for several days. After the dextrose has crystallized, the mother liquor is removed by centrifugation. The practical details for obtaining the final product, crystalline dextrose, reworking the mother liquor and controlling the crystallization are all contained in the writings and patents of Newkirk. Probably the most important factor in Newkirk's work was the discovery that, if the crystallization was allowed to take place while the system was being agitated and if the concentration of the sugar solution was high, dextrose would crystallize and a chemically pure product would be obtained.

As this work was continued, conditions were worked out which favored the production of beta-dextrose. This particular crystalline form of dextrose has the property of dissolving easily and rapidly in water. Its use in beverages and other products requiring ease of solution followed immediately.

QUALITY CONTROL TESTS

The corn refining industry has come a long way since the days when the Duryea plant had two tests, a taste test for alkalinity in the starch

settlers and a taste test for sweetness in the conversion process. A listing and explanation of some of the tests now being used routinely will illustrate this point.

The standard tests listed in Table 75 have been approved by an industry analytical committee and are run on the materials indicated. In addition to those tests listed in the table, many other tests which apply only to corn syrup, have industry-wide standard methods. Some of these are: Baumé, calcium, chloride, color, copper, dextrose equivalent, heavy metals, iron, fermentables, refractive index, specific rotation and sulfate.

TABLE 75

STANDARD ANALYTICAL PROCEDURES

	Corn	Cornstarch	Corn Syrups	Feedstuffs
Ash	x	x	x	x
Moisture	x	x	x	x
Protein	x	x	x	x
Insect infestation	x			x
Starch	x			x
Acidity		x	x	x
Crude fat		x		
Total fat		x		
pH		x	x	x
Solubles		x		x
Sulfur dioxide		x	x	

In addition to the standard tests mentioned above, there is a list equally as large which includes tests being used regularly, but which have not had enough industry-wide "round-robin" type of collaborative testing to be approved as standard methods. Work on developing new standard methods and on improving present ones is constantly being done.

In connection with the search for new and better analytical tools, it should be mentioned that the corn refining industry, through the Corn Industries Research Foundation, Inc., pioneered the development of the application of nuclear magnetic resonance techniques to the determination of moisture in cornstarch. This work has resulted in the manufacture of a commercial instrument which will determine moisture in cornstarch, flour and similar materials in one minute with better precision than is obtained with standard methods in much longer times. An instrument which will measure nitrogen directly is in a preliminary stage of development. Other new testing procedures which are in the research stage are the use of ultrasonic vibrations to characterize starch pastes and the use of differential thermal analysis and thermogravimetry to identify and define solid carbohydrate materials.

PRODUCTS AND THEIR USES

The products of the corn wet-milling industry fall into three main classes in their uses. The classes are industrial, foods for human consumption, and animal feeds. The largest industrial consumer of cornstarch is the paper industry. The ever increasing demand for stronger and more printable paper has resulted in the use of more and more cornstarch in paper making.

Starch is added to the pulp in the beaters of the paper mills. The purpose of the starch in this operation is to increase the strength of the sheet, add "rattle" to the paper, and increase the resistance to tearing. This latter property has become more and more important as the manufacturing processes in the mills have been stepped up to get more and more production. The giant paper mills of today could certainly not operate on the raw material which was fed to the rolls before the use of starch became universal.

Another use of starch in the paper industry is in the manufacture of coated products. These coated papers are necessary in the high-speed printing processes which are used today because the coatings increase the tensile strength of the roll of paper. Without the coatings, the paper would be torn to bits by the rolls and their inks.

Another large user of starch is the textile industry. The textile weaving operation has an abrasive action on the fibers being used. To counteract this, the fiber is passed through a hot bath of cooked cornstarch and then dried. The fiber, with its coating of cornstarch, is then ready for use and will not fray or part during the weaving as does the unsized material. Starch is also used for "backfilling" of textiles. This "backfilling" gives a firm "hand" to the cloth and improves its appearance. It also causes the material to handle better in its further processing operations.

Other industrial users of cornstarch are commercial laundries, foundries where starch is used as a core binder for molds, mining operations where starch is used in the ore flotation process, petroleum producers where starch is used as an ingredient of the drilling muds, the adhesives industry, and many others such as pharmaceutical pelleting, briquette cementing, and match manufacture.

Corn syrup, although used principally in the food industry, does have some important industrial uses. It is used by paper mills as a plasticizing agent in the manufacture of glassine paper. Here it functions by maintaining the proper humidity in the paper so that it remains flexible. It is used in pharmaceutical preparations as a carrier for the active ingredients, in the leather tanning industry, and as a textile finishing agent.

Dextrose is used as a raw material in the manufacture of the polyols, sorbitol and mannitol. Catalytic hydrogenation reduces the dextrose to the alcohols. Sorbitol has many uses based on its humectant properties, and is itself used for the production of surfactants and synthetic vitamin C.

The use of cornstarch, corn syrups, and corn sugars in the food industry are so numerous that only a few of the largest ones will be mentioned.

The candy industry is a tremendous user of corn syrup and corn sugars. This industry consumes about one-half of all the corn syrup produced and sold today. It is estimated that one-fourth of the total weight of candy produced is corn syrup. The reasons for the large use in this industry are well understood. Corn syrup has the ability to suppress crystallization of sugars so that the candy retains its smooth texture. The use of corn syrup gives the advantage of excellent batch-to-batch uniformity, which some of the older methods did not do. Another reason for using corn syrup is because of its humectant properties which maintain the original moisture levels in the candies and thus prevent drying and brittleness.

Other food uses of corn syrup are in the production of mixed syrups, bakery products, jams, jellies, preserves, ice cream, and canned and frozen fruits.

Dextrose and corn sugars are widely used in bakery products such as bread, doughnuts, cookies, biscuits, and prepared mixes. They are also used in soft drinks, frozen and preserved foods, and ice cream.

Cornstarch also has many food uses in addition to the industrial uses mentioned above. It is used in custards, puddings, soups, cake fillings, and salad dressing. The brewing industry uses a special product, refined grits, because of its low protein and fat content. This property imparts very good keeping qualities to brewery products. Cornstarch is also used in baking powder and bakery products as well as in candy manufacture.

The steepwater which has been mentioned many times has some interesting uses. It is concentrated to a pea soup consistency and used as a mold-nutrient, finding a particular use in the manufacture of penicillin. The materials in steepwater are the solubles extracted from the corn and include protein, carbohydrate, and minerals. In addition to its widely publicized use in penicillin production, it is an important ingredient of high-quality animal feeds.

Corn oil has not been discussed in this chapter because its manufacture is being covered in another chapter. However, it should be mentioned here that corn oil is one of the more unsaturated oils and finds large uses in salad dressing and cooking oil applications. It has been used in many of the studies dealing with the effect of saturated and unsaturated fats

on various animals and is high on the list of those oils containing large amounts of essential fatty acids.

Dextrins and modified starches are also being covered elsewhere, but it should be pointed out that the wet-milling industry offers a wide variety of special carbohydrate materials which are particularly adapted to specific applications. Thin-boiling starches, cross-linked starches, and starch derivatives merit individual mention.

A word should be said about starch produced from waxy maize. Waxy maize is a type of corn which has a carbohydrate component made up mostly of amylopectin, the branched molecule of ordinary cornstarch. This type of starch, without the linear amylose molecules, has properties quite different from regular cornstarch. The starches from waxy maize form clear, fluid pastes in contrast to cornstarch which forms pastes which are cloudy and gelatinous. Waxy maize starch is used in adhesives and textile finishing, pie fillings, and salad dressings.

The animal feeds which are produced by the corn wet-milling industry are far better nutrients than the corn with which the refiners start. The reason behind this is obvious. The refining process does an excellent job in separating carbohydrate from protein and consequently, the feed products are much higher in protein than the corn itself. Corn grain has about 10 per cent protein, but corn gluten feed has 21 per cent, and corn gluten meal 41 per cent protein. Thus, the feeds are higher in protein and lower in carbohydrate, which is exactly what is desired. The feed products are sold to the mixed feed industry which then makes the necessary adjustments so that the end product is a balanced feed best suited to the particular animals to whom the product goes.

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Richard I. Meyer

Production of Oils from Cereal Grains

Oils derived from cereal grains constitute important products in commerce but their total world production is considerably below levels of output for many other vegetable, marine and animal oils and fats. These oils, corn, rice and wheat, are produced over a world wide area. Corn oil is produced in its largest quantities in the United States (Jamieson 1943) although such countries as the Union of South Africa, U.S.S.R., Argentina, and Canada manufacture small amounts of it. In 1957, production of corn oil in crude form in the United States was estimated to be 275 million lbs. (Anon. 1957). World production of rice oil has been estimated to be less than 50 million lbs. (Bailey 1951A) and wheat oil production throughout the world has been estimated to be approximately 600 thousand lbs. (Levin 1958). Of edible oils from vegetable sources produced in the United States, those from the soy bean and cottonseed each greatly exceeded the total output of corn, rice and wheat oils.

Were it not for the fact that during the preparation of by-products from corn, the germ is almost completely separated from the rest of the products, corn oil would not have become an important oil from a commercial standpoint (Jamieson 1943). Wheat germ oil has no significance as a food and is only of very minor economic importance (Levin 1958). Although of greater significance in other parts of the world, principally in the orient, rice oil has not yet reached a level of great commercial importance in the United States (see p. 444).

It can be readily seen from the foregoing facts that corn oil is the only oil produced from the true cereal grains which is of real economic importance in the United States.

SOME CHARACTERISTICS OF THE CEREAL OILS

Classification of Cereal Oils

Vegetable oils and fats are difficult to classify according to a plan which takes into account the many factors which would simply and completely describe them. In Table 76 are set forth two attempts at classifications of the three oils obtained from cereal grains having production significance in the United States.

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Table 76

CLASSIFICATION OF THREE CEREAL OILS[1]

Oil[2]	Chemical Group or Type[3]	Botanical Name[4]
Corn	Oleic-linoleic acid	*Zea mays*
Rice	Oleic-linoleic acid	*Oryza sativa*
Wheat	Linoleic acid	*Triticum sativum*

[1] All of these oils fall into the Hilditch Classification Group IVa, mono- and di-ethylenic and saturated fatty acids (containing principally oleic, linoleic and palmitic acid components). See Dean (1938).
[2] All of these oils are derived primarily from plants cultivated or processed in the main for products other than the oil.
[3] Bailey (1951A).
[4] Williams (1950).

Although the cereal grain oils are sometimes classified as semi-drying type oils on the basis of their iodine values, such a system of classification fails to take into account a number of rather important distinctions. These cereal oils contain principally oleic, linoleic and palmitic fatty acid constituents, in that order (except for wheat oil, where the linoleic acid content slightly exceeds that of oleic acid), while linoleic acid or other fatty acids of greater unsaturation than linoleic are entirely absent from corn and rice oil. Table 77 indicates the disposition of the principal fatty acid components in corn, rice and wheat oil. It has been thought that, since these oils do not contain linolenic acids or other highly unsaturated fractions, they are quite free from the tendency toward flavor reversion which is found in soybean and similar oils.

Corn Oil

Crude corn (or maize) oil has a dark reddish amber color. Even after refining, it is considerably darker than many other vegetable oils. By applying strong bleaching action, however, it can be lightened to a golden yellow color. This oil, unless subjected to considerable deodorization, retains the strong taste and odor characteristic of the original corn kernel. The unrefined oil contains relatively large amounts of phosphatides and other non-oil substances (often in excess of two per cent) and its free fatty acid content (usually above 1.5 per cent) is higher than that found in most vegetable oils. The refined oil contains small amounts of waxes which cause the oil to cloud at refrigerator temperatures unless it is selectively removed by a process called winterization. This process will be described in a later portion of this chapter. The keeping quality of refined corn oil is fairly good. The crude oil, however, is rapidly hydrolyzed, unless processing proceeds without delay. Such degradation is enhanced when the oil remains in the presence of corn meal impurities. The germ portion contains from 30 to 50 per cent of the oil of the corn kernel. Table 78 shows the oil content of various portions of the corn,

TABLE 77

PRINCIPAL FATTY ACID COMPONENTS IN CORN, RICE AND WHEAT OILS

	Saturated acids		Unsaturated acids			
Oil	Palmitic Per cent	Stearic Per cent	Oleic Per cent	Linoleic Per cent	Linolenic Per cent	References
Corn	7.8	..	46.3	41.8	..	Dean (1938)
	12.0[1]	..	45.0	42.0	..	Hilditch (1949)
	11.0	2.9	48.8	34.0	..	Longenecker (1939)[2]
	8.1	2.5	30.1	56.3	..	Bauer and Brown (1945)
Rice	18.0	2.8	48.2	29.4	..	Dean (1938)
	17.1[1]	..	46.3	33.1	..	Murti and Dollear (1948)
	11.7	1.7	39.2	35.1	..	Jamieson (1926)[3]
	16.5	1.7	43.7	26.5	..	Jamieson (1943)[4]
Wheat	..	16.1	28.2	52.2	3.5	Dean (1938)
	13.8	..	30.0	41.1	10.8	Dean (1938)
	16.4	5.6	11.5	57.3	29.2	Gunstone and Hilditch (1946)
	..	15.5	25.5	52.6	6.3	Radlove (1945)

[1] Undesignated saturated fatty acids.
[2] Data are in mol. per cent.
[3] Rice plant variety: American.
[4] Rice plant variety: Hambus.

TABLE 78

OIL CONTENT OF THE WHOLE SEED AND THE VARIOUS PORTIONS OF CORN, RICE AND WHEAT

	Portion of the Grain		
Oil	Whole Per cent	Bran Per cent	Germ Per cent
Corn	3–5.5[1]	...	30–35[1]
	3–6.5[2]	...	40–50[3]
Rice	14[3]	8–16[2]	...
Wheat	2[2]	5– 6[2]	12–18[2]

[1] Williams (1950).
[2] Jamieson (1943).
[3] Bailey (1951A).

TABLE 79

CHEMICAL AND PHYSICAL PROPERTIES (WITHIN USUAL LIMITS) FOR CORN, RICE BRAN, AND WHEAT GERM OILS

Property	Corn	Rice Bran	Wheat Germ
Solidifying point, °F.	5–14	2	...
Refractive index (Zeiss at 104°F.)	58.5–60.5	61–68	72–80
Specific gravity 59.9/59.9°F.	.922–.926	.918–.928	.928–.938
Titer	57–61[1]	77.4[2]	...
Iodine value	105–125	92–109	115–125
Saponification value	189–193	179–193	185–192
Unsaponifiable matter, Per cent	.8–2.0	2.7[3]	2–5
Free fatty acids, Per cent as oleic	1.0	5–50	..

[1] Hilditch (1949).
[2] Murti and Dollear (1948).
[3] Williams (1950).

rice and wheat plant. Table 79 indicates the many physical and chemical properties peculiar to corn, rice and wheat oils.

Rice Oil

The color of rice oil, in either the refined or the crude state varies to a considerable extent. Oils which have attained a comparative degree of acidity are difficult to refine, and, in particular, to bleach to a color considered acceptable for an edible oil. It is held that the oil extracted from rice is invariably high in its free fatty acid content (Bailey 1951). This high acidity is attributed to the activity of an unusually active lipase. It has been claimed, however, that if caustic refining of the rice oil is accomplished soon after extraction, much of this lipolytic activity is retarded (Jamieson 1943). However, once processed the oil is reputed to possess unusual stability. Bailey (1951) suggests that this property is probably due to the presence of some potent antioxidants naturally present in the rice oil. Table 79 shows some physical and chemical properties of rice oil. Feuge and Reddi (1949) have shown that a tasteless and odorless oil can be produced through conventional refining, bleaching and deodorization of the oil.

Wheat Oil

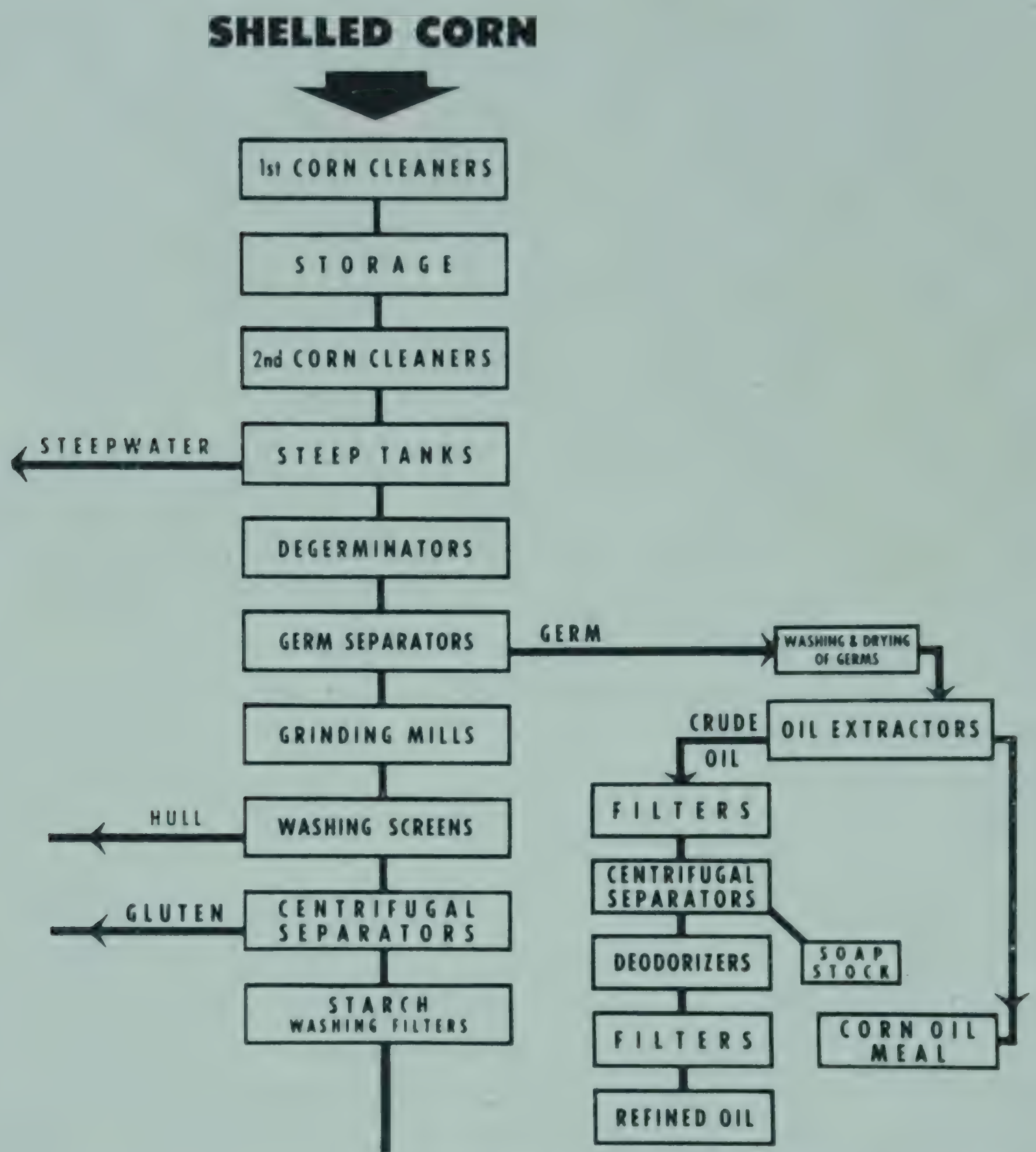
As shown in Table 77 wheat oil, unlike corn and rice oil, does contain appreciable amounts of linolenic acid. The presence of this substance suggests potential problems with the keeping quality of the oil. Williams (1950) has found that wheat oil becomes rancid easily. The problems of palatability have not been a serious obstacle to its use because wheat oil is marketed, in the United States at least, principally as a specialty product for nutritional supplementation. Table 77 shows the principal fatty acid components of wheat oil. Table 79 indicates some chemical and physical properties peculiar to wheat oil.

COMMERCIAL PRODUCTION OF CEREAL OILS

The separation of oils and fats from vegetable materials comprises a distinct and specialized branch of fat and oil technology. All extraction processes have certain objects in common which may be mentioned briefly here: 1) to obtain the oil uninjured and as free as possible of undesirable impurities; 2) to obtain the oil in as high a yield as is consistent with the economic realities of the process; and 3) to produce an oil cake or residue of the greatest possible value as a by-product (Bailey 1951).

Production details of rice and wheat oil manufacturing will not be given within this brief survey, because essentially the same steps are used

in extracting and refining of rice bran and wheat germ oils as are used for corn oil. Fig. 92 illustrates the general scheme for processing of the corn germs following their separation from the corn kernel.

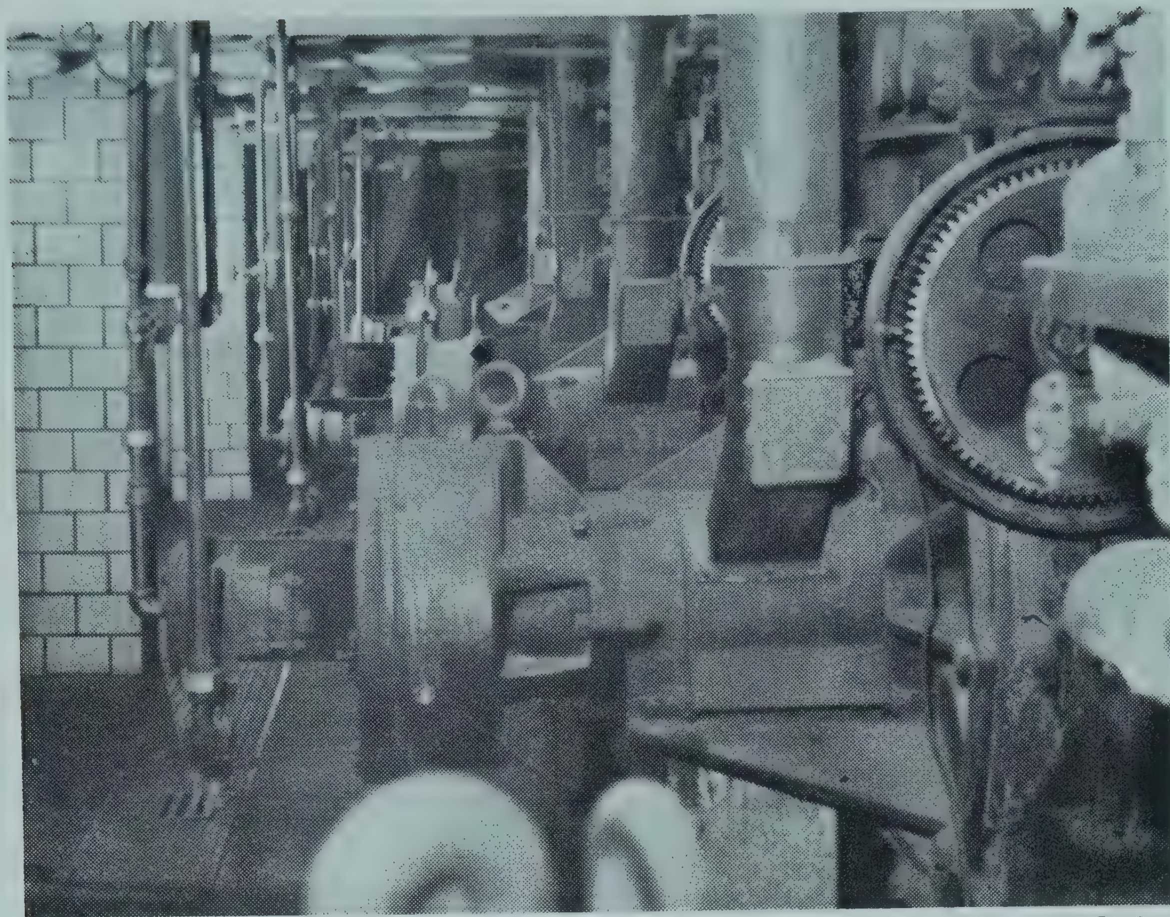


Courtesy of Corn Industries Research Foundation

FIG. 92. FLOW SHEET SHOWING EXTRACTION AND REFINING OF CORN OIL IN THE WET-MILLING PROCESS

The raw material for corn oil extraction is the germ after it has been separated from the corn kernel. Following this step, the germs are washed and dried. They are then heated prior to their delivery into oil extraction presses. The oil may be expressed through hydraulic presses, but the usual practice in the United States is to employ semicontinuous or continuous screw-type presses. Such presses are called Anderson expellers. Fig. 93 illustrates these presses operating during production.

In utilizing the Anderson expeller, the germs are first passed through a set of flaking rolls until they are macerated into a coarse meal. This ground material is then passed into steam-heated temperers and then into the expeller unit. Here, the germs are forced under high pressure



Courtesy of Corn Industries Research Foundation

FIG. 93. ANDERSON EXPELLERS USED IN CORN OIL EXTRACTION

through a slotted barrel made up of steel sections in the form of a rotating screen called the "oil-reel." During this stage of processing, most of the oil is pressed out through the slots, while the fibrous portions (called the "foots") are discharged at the end of the barrel. This rejected material is usually returned through the expeller unit for repressing, but ultimately this residue material still retains about 5 to 8 per cent of its original oil content.

Upon leaving the expeller units the crude oil is usually pumped through a lengthy filter press. Fig. 94 illustrates an installation of corn oil clarifying presses. This filtration constitutes only the first of several such steps throughout the entire refining process (Jamieson 1943, Anon. 1957).

Some refiners employ a combination of mechanical presses and solvent extraction for removing oil from the grain germs. Solvent extraction is a highly efficient means of recovering the oil for it is capable of reducing the oil content of the residue to about 0.5 per cent as compared with 5 per cent in mechanically-expressed residues. Although solvent extraction is particularly advantageous in the processing of raw materials of extremely low oil yield, this process has been extended to the processing of corn germs in recent years (Bailey 1951A). It is a common practice to "pre-press" seeds of high oil content in low-pressure screw presses to about ten per cent residual oil content prior to solvent extraction.

The usual solvents employed in this process are the so-called extrac-

Courtesy of Corn Industries Research Foundation

Fig. 94. Filter Presses for Clarifying Corn Oil

Courtesy of Corn Industries Research Foundation

Fig. 95. Centrifuges and Flowmeters Used in Corn Oil Refining

tion naphthas such as light petroleum fractions consisting chiefly of *n*-hexane.

The solvent-oil mixture from the extractor is filtered to remove any solid matter, and then the solvent is separated from the oil in an evaporator or stripping column (Anon. 1957). Here the solvent boils off, and the vapor is condensed and collected for re-use. The germ flake from the extractor contains a certain amount of solvent and this is usually recovered by a steaming and heating process. The extracted flake, now stripped of almost its entire oil content, may be used in livestock feeds. Sometimes, in place of filtering the oil from the solvent extractor, it is simply run into large tanks where the solids settle to the bottom and are subsequently drawn off. These solids, known collectively as "foots," are utilized in soap manufacture.

Further refining of the extracted oil must be undertaken to remove fatty acids, phosphatides and other gummy or mucilaginous materials. The first step in fatty acid removal is to expose the oil to a strong caustic aqueous alkali solution (Bailey 1951A). This process involves three operations: 1) emulsification of the oil with a considerable excess of alkali material; 2) heating to break the emulsion; and 3) separating the refined oil from the precipitated soapy substances and miscellaneous associated impurities. The precipitated material is again termed "foots" or "soapstock" and has commercial by-product value, for it contains about 30 to 50 per cent free and combined fatty acids. Separation of the refined oil from the impurities is accomplished by centrifugation. Fig. 95 illustrates an installation of centrifuges and flowmeters used in this stage of the refining process. By means of the alkali treatment for fatty acid removal, crude oils which seldom would contain less than 0.5 per cent free fatty acids are reduced to a free fatty acid level of about 0.01 to 0.03 per cent. Significant improvement in production efficiency has been obtained in recent years through the introduction of a continuous method of caustic soda refining to replace the more conventional batch method. This newer technique, first introduced into the United States in 1933, prevents to a large extent the so-called neutral losses which are common in the batch technique. These losses are reduced about 25 to 30 per cent by reducing the time of contact between the corn oil and the caustic material and through efficient separation of the oil and the soapstock in very high-speed centrifuges.

A bleaching treatment of corn oil is usually required, since the alkali-refining process does not produce a sufficiently light-colored oil for marketing purposes. Bleaching is usually accomplished by treating the refined oil with an adsorbent material in powder form. Both natural and acid-activated bleaching earths (e.g., Fuller's earth or clay) are used as

adsorbents. The acid-treated powders are more expensive, but have a greater adsorptive power for fat pigments, particularly for chlorophyll or related pigment compounds. The bleaching is usually effected at a temperature of 220 to 240 F. under atmospheric pressure. Slightly lower temperatures may be utilized when the process is done under vacuum. When a good activated adsorbent earth is employed, an amount of only about one per cent is required to bleach a good quality of oil. However, considerably larger amounts of earth material may be required if a natural earth of lower activity is used, or if the oil is of a poor grade or highly colored. Equilibrium between unadsorbed pigments in the oil and adsorbed pigments in the earth is usually established within a five-minute period if the oil and adsorbent are vigorously mixed.

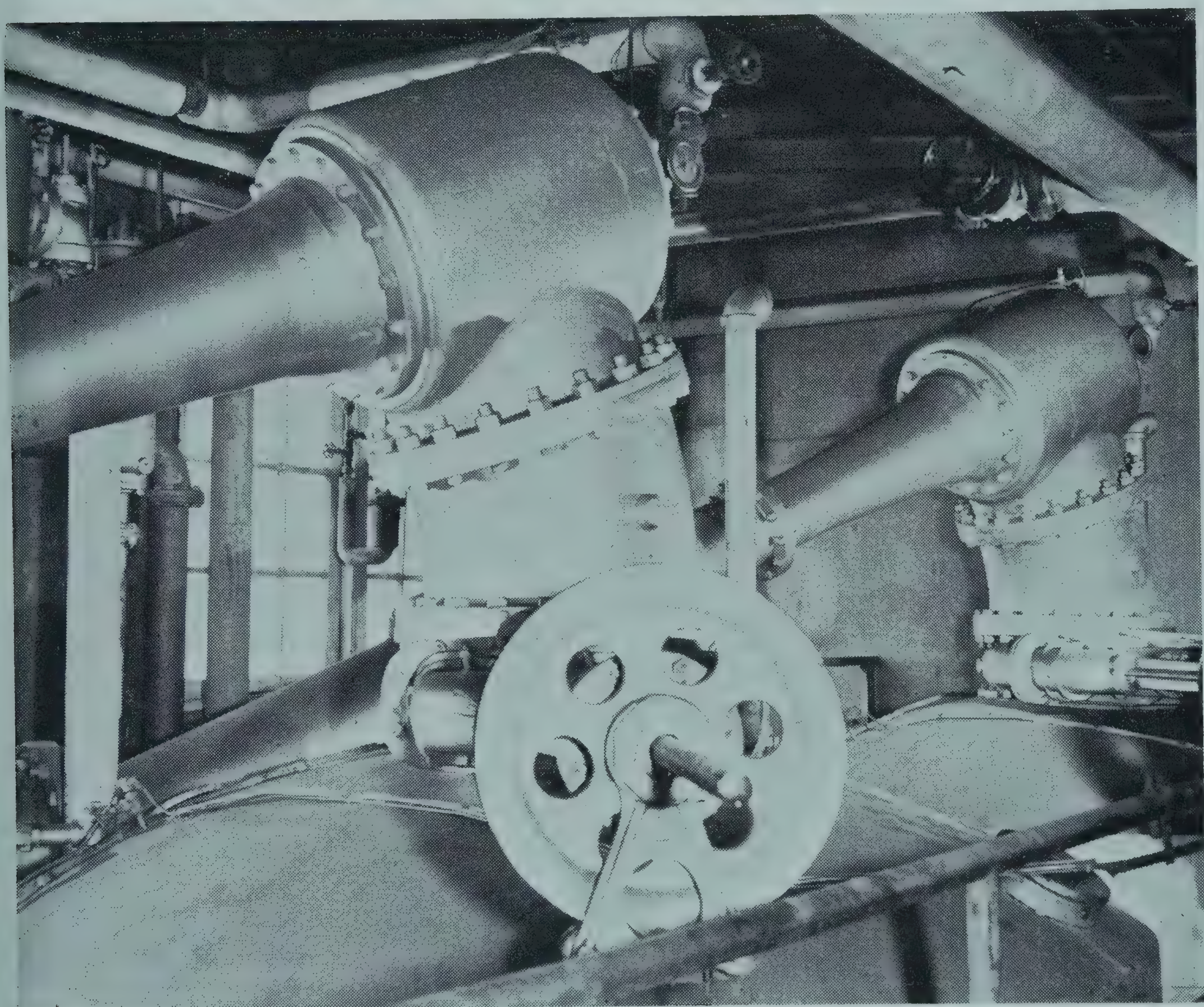
In the common practice of bleaching, on a batch basis, the oil and adsorbent are mixed together in a kettle of about 30,000 lbs. capacity. To avoid oxidation of the oil and improve bleaching efficiency this procedure is usually performed under a vacuum, although the use of open kettles for the operation is not uncommon. The charge is pumped from the kettle through a filter press. The press cake of spent adsorbent is blown with air, or a mixture of steam and air, to reduce its entrained oil content to a level of 30 to 40 per cent. Following this effort to recover oil, in some commercial operations solvent extraction is carried out on the press cake to recover more oil. Ultimately, the press cake of adsorbent earth material is discarded.

Bleaching as a distinct step in the oil-refining process is usually followed by a chilling treatment of the oil called "winterization." Winterization or destearination are the terms generally applied to a process of removing from the oil certain constituents which, though soluble at medium or higher storage temperatures, crystallize out and make the oil turbid in appearance under conditions of cold (Andersen 1953). Particularly when edible oils are used as salad oils, a small fraction of solid glycerides must be removed, as their presence makes the oil appear cloudy. In corn oil, however, it is not so much the presence of high-melting glycerides as a very small portion of waxes which produces this undesirable turbidity.

The process of winterizing consists in cooling the oil at temperatures some degrees below that at which the oil is required to remain clear. The oil is cooled with a cold water or brine coolant, or by cooling the air in a storage room where the oil is maintained. The cooling must be slow enough to enable the higher melting components to form definite well-built crystals. Small crystals resulting from too rapid cooling make filtration difficult. Frequently, a suitable filter aid is added to the oil before cooling, so that the particles can act as crystallization centers. To ensure

maintenance of the low temperatures during filtration, the filters are often placed in the cooling room or else the filter presses are provided with internal channels for cooling. No wholly satisfactory continuous process for winterizing (Schwitzer 1951) has been perfected.

The final step in the refining process is usually the deodorization of the oil. Practically all of the vegetable oils used as edible fat products in the United States, as well as in most western nations, are subjected to a deodorizing treatment.



Courtesy of Corn Industries Research Foundation

FIG. 96. TOP OF OIL DEODORIZING KETTLE SHOWING VACUUM PRODUCING STEAM JETS

Deodorization is a process of steam distillation in which the relatively non-volatile oil is held at a high temperature, under reduced pressures, while it is stripped of the relatively volatile constituents responsible for flavors and odors in the crude or partially refined oil. Concomitant with the deodorization process, the free fatty acid content of the oil is usually reduced to a level of from 0.01 to 0.03 per cent and bleaching or loss of color of the oil also will occur (Bailey 1951A).

Modern deodorization equipment operates in the temperature range of about 425° to 475° F. and at very high vacuum levels. Many processors deodorize salad and cooking oils at somewhat lower temperatures than they do hydrogenated oils. The rigorous exclusion of oxygen during this process may be regarded as essential to the effectiveness of the operation. Fig. 96 illustrates the steam jets which produce the vacuum at the top of a typical deodorizer vat.

The stability of vegetable oils of good quality is usually improved considerably by the deodorization process (Bailey 1951). Deodorization destroys any peroxides in the oil and removes aldehydes or other volatile products which may have developed through atmospheric oxidation, but it should be noted that strongly rancid oils cannot be completely reclaimed by deodorization.

Batch-type processes are yielding to newer continuous processes for deodorization. In the former, the steps of heating, deodorizing, cooling and filtering may take from 5 to 8 hours depending on the actual conditions of operation, the size and the quality of the equipment (Schwitzer 1951). Development of semi-continuous or continuous units with automatic controls have resulted in complete deodorization being effected in $2^1/_2$ hours. If deodorization has been properly conducted, the removal of odoriferous ingredients from the oil is substantially complete. Well deodorized oils of different identity, when fresh, cannot be easily distinguished from one another by odor and taste. They are quite bland and merely give one a sensation of oiliness in the mouth (Bailey 1951).

Corn oil, following deodorization, is usually cooled and finally packaged. Only a small portion of the total edible corn oil produced in the United States is subjected to the process of hydrogenation, and thus, as a processing step in the general refining of vegetable oils, it will be mentioned here only briefly. Primarily, hydrogenation is a means of converting liquid oils to semi-solid plastic fats suitable for shortening or margarine manufacture. By means of this process, enhancement of the oil stability and lightening of color is achieved. In the hydrogenation process, hydrogen is added at the double-bonds in the fatty acid chains. Hydrogenation as a process is more than a means of producing substitute products, for hydrogenated fats may be tailor-made to produce products superior in some important aspects to any of the natural plastic fats.

QUALITY CONTROL AS APPLIED TO CEREAL OILS

Business transactions in crude and refined oils in the United States are conducted with the aid of uniform standards, specifications, and trading rules established by various trade organizations, government and associated scientific or technical societies. The trading rules generally set

forth specifications for different grades of each oil and in some cases include systems for the establishment of premiums or penalties based on the contract price for oil which is better or poorer in quality than the standard for a common basis grade.

Although not directly concerned with oil trading, the American Oil Chemists' Society has for many years been active in the development of analytical methods which are generally the basis for trading rules utilized by the industry. Official and tentative test methods (AOCS) commonly used in examining and evaluating the various properties of corn oil or other vegetable oils include:

Free Fatty Acids and Acid Value

These are quantitative measurements of the amount of uncombined free fatty acids present in the oil. The determination of the residual free fatty acids and acid value serves as a measure of the effectiveness of the total refining procedure. The acid value is defined as the number of mg. of potassium hydroxide necessary to neutralize one gm. of the oil.

Color

Color is important not only in the appearance of the oil itself, but also as it affects the color of the product to which the oil may be added. The bleaching step in the refining process is varied according to the color in the oil which is actually desired. Although there are many methods for measuring color, it has been customary to report color in edible oils in terms of Lovibond units. This method expresses the color in a sample by comparison with red and yellow Loviband glasses of known intensity.

Cold Test

This test measures the ability of an oil to remain sparkling clear at refrigeration temperatures. It is a check on the effectiveness of the removal of solid glycerides and wax during the winterization process. The test is made by actually holding a sample of the oil for $5^1/_2$ hours at 32°F. and then observing for any cloudiness or turbidity.

Peroxide Value

This is a measure of the degree of oxidation that has taken place in the oil. Oxidation is related to rancidity and the test is indicative of the age of the oil in terms of probable handling conditions that have ensued (including temperature and exposure to light and air).

Smoke Point

This value represents the temperature at which the oil first gives off a continuous stream of smoke. The value is fairly constant for each

particular type of oil and is indicative of the performance of an oil for deep fat frying applications.

Table 80 shows typical analytical data covering the basic properties of corn oil (Anon. 1957).

TABLE 80

REFINED CORN OIL ANALYTICAL DATA[1]

Property	Value
Acidity (free fatty acid as oleic)	0.020 to 0.050
Acid value	0.04 to 0.10
Color (Lovibond)	20 to 25 yellow 2.5 to 5 red
Cold test	Clear
Saponification value	189 to 191
Iodine value	125 to 128
Hehner value	93 to 96
Titer	64 to 68 °F.
Melting point	4 to 12 °F.
Smoke point	430 to 500 °F.
Solidifying point	−4 to 14 °F.
Flash point	575 to 640 °F.
Fire point	590 to 700 °F.
Specific gravity	0.918 to 0.925
Pounds per gallon	7.672 at 70 °F.

[1] Anon. (1957).

UTILIZATION OF CEREAL OIL IN FOODS AND FEEDS

As shown by the data in Table 77, the fatty acid composition of corn, rice bran and wheat germ oil is quite similar. If the separate oils were refined by modern techniques to a high degree of quality, their acceptability and perhaps their utilization would follow a similar pattern. However, as stated earlier, the production of rice bran oil is very sparse in western nations. In the case of wheat germ oil, it is consumed almost exclusively as a nutritional supplement, particularly for its vitamin E content, and cannot be considered as a common food. Thus discussion of utilization of cereal oils will be principally confined to that of corn oil.

Salad Oils, Cooking Oils and Salad Dressings

Almost all of the corn oil available is made into a salad or cooking oil (Bailey 1951). For these two purposes the oil is identical, except that when destined exclusively for salad use, the oil is winterized. The large use of corn oil for these purposes is due in part to the fact that the oil requires little or no winterization treatment, and partly because the natural color of the corn is rather darker than is desirable for use in hydrogenated oils. Corn oil reputedly displays a high resistance to rancidity, which makes it especially valuable as an ingredient in products like mayonnaise or semi-solid salad dressings (Anon. 1957). Despite properties of

corn oil which seem to show its advantage in these latter products, recent surveys conducted under joint auspices of industry and government (Danielson and Knape 1958) indicate that corn oil comprises less than five per cent of the total vegetable oil usage in the United States for mayonnaise, salad dressings, and related products. It should be pointed out that this situation is governed almost entirely by the spread in price between corn oil (on the high end) and soybean and cottonseed oils (on the low end). In the highly competitive food market a price differential of ten per cent or more in a major ingredient like edible oils for these high fat products can and does favor the use of less expensive sources of oil.

Bakery Products

In the United States corn oil is used directly as a liquid fat, or is sometimes blended with harder fats. Bakers use the oil for greasing tins or for brushing baked goods. Actually the commercial bakery use for corn oil is quite small in terms of the total annual production of corn oil. In recent years there has been an increasing utilization of corn oil in the liquid state by homemakers in contrast to use of hydrogenated fat sources.

Frying and Fried Products

A high smoke point (see Table 80) makes corn oil a preferred medium for deep-fat frying. The relatively high frying temperatures that may be used here, coupled with the other favorable characteristics make this oil particularly good for making potato chips and doughnuts. The corn oil may be used repeatedly for frying, since it does not tend to absorb flavors from one food and transmit them to another.

Animal Feeds

A considerable use is made in the animal feeds industry of the by-products of cereal oil production. The pressed germ meal cakes obtained in the early stages of both corn and wheat germ oil refining have proved to be of real value as a source of metabolites and food calories for use in prepared feeds.

Other Uses

The extensive use of the by-product of corn oil production referred to as soap stock, in the manufacture of soap and associated products, represents the most important non-food application of corn oil. Smaller quantities of either crude or refined corn oil are used in ammunition, chemicals and insecticides, paint and varnish substitutes, rust preventive compounds, and textiles. Sulphonated corn oil has important application in

tanning and processing of leather. Refined corn oil has found wide usage as a carrier for vitamins and in other medicinal applications.

FUTURE PROSPECTS FOR CEREAL GRAIN OILS

Further commercial inroads of cereal oils can be expected to be limited, in their application as a food, because of the increasing pressures of availability of less expensive vegetable oils of high quality. From an economic standpoint, likewise, inherently limited yields of oil present deterrents to the commercial production of cereal oils, particularly since highly competitive edible oil sources are available.

It would seem that a yet unrealized day of usefulness for the cereal grain oils might be dawning. This may result from their significant biological value as sources of nutritive factors (Levin 1958). Although cereal oils contain important sterols and essential unsaturated fatty acids, physiologists have only recently begun to find experimental evidence for what appear to be peculiar properties of these oils. Such studies show the favorable influence of certain constituents of the cereal oils in studies on heart action and reproduction in chickens (Jensen *et al.* 1958). Confirmation of such unique properties might open new uses for the cereal oils which could afford them a position of significance in the food field as well as in that of therapeutic nutrition.

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Bruce W. Smith

Feed Manufacture

INTRODUCTION

Only 15 per cent of the cereal grains raised in the United States are consumed by man. The remaining 85 per cent goes almost exclusively into the feeding of livestock and poultry.

The American manufactured feed industry combines cereal grains and cereal mixtures with other ingredients, including products containing vitamins, both natural and synthetic, and drugs, to produce what are termed "formula" or "mixed" feeds. Millions of farmers still feed some straight grain to their stock, although their number is decreasing as more is learned about the economic advantages of using commercially-prepared rations.

The average farmer cannot afford to purchase the grain processing equipment which is essential to the proper preparation and combination of the elements which make up nutritious, economical feed.

Early History

The formula feed industry is comparatively new. Wherry (1947) noted that, "Sixty years or more ago, the flour mills in Minneapolis dumped wheat bran into the river because nobody wanted to buy it. Cottonseed meal was used as a fertilizer, if used at all. Most of the linseed meal was shipped to Europe. Large milk companies did not permit the feeding of gluten feed to dairy cows."

Wherry continued, "But men of vision realized that a new era in poultry and livestock production could be built on the efficient utilization of these precious proteins that were wasted in an earlier day. And so it was that the golden age of better feeding began."

Old-timers in the feed business say that the history of cereal use in feed or as feed actually goes back to 1888, when Buffalo, New York, was swept by flood waters. The floods followed the great March snowstorm of that year, and their waters swept out of some of the mills which they invaded, traces of the gluten by-product of corn processing. Animals in stables, cow barns, and sheds in the vicinity reportedly drank freely of these gluten-impregnated flood waters and gained weight or milked at record rates. Within weeks, a new by-product business was launched

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by the Buffalo corn mills: the shipping throughout the eastern United States of boxcar loads of wet gluten feed.

First Dry Feeds

Dry feeds, used almost exclusively today, gained little prominence until early in the 20th century. However, an ambitious Buckeye, one Ferdinand Schumacher of Akron, Ohio, had produced and sold a dry cereal mixture some years earlier.

Schumacher was a cereal miller. He processed oats, corn, barley, and wheat for human consumption. In about 1885 the cereal miller brought out what he labeled "COB Feed," the capital letters standing for the ingredients: corn, oats, and barley milling by-products.

Schumacher reasoned, and correctly, that because the primary milled cereals were valuable in human nutrition, the by-products no doubt had some value left in them which could be utilized by poultry and livestock. But the Ohio miller was years ahead of his time, feeding-wise, and it was not until after 1900 that the dry feed industry began to make any noticeable progress. There was still a long way to go. In 1908, for example, a chick feed was advertised as being made of oats, corn, wheat, flax, millet, kafir, "etc." That "etc." may have been entirely permissible in those days but careful state government supervision would not allow it today.

Corn gluten feed became one of the first dry protein cereal products to be fed to livestock. This product then, and now, consisted of shelled corn with most of the starch, gluten, and germ removed by wet-process milling. A giant of American industry, Corn Products Company, has been marketing Buffalo brand corn gluten feed for half a century.

First Manufacturers

The oldest feed manufacturing company in continuous operation in the United States is Blatchford's of Waukegan, Illinois, which was founded by John W. Barwell, an Englishman, in 1875. National Food Company at Fond du Lac, Wisconsin, was established ten years later.

The firm which today is by far the largest manufacturer of animal and poultry feeds is Ralston Purina Company of St. Louis. It was founded in 1894 by the late William H. Danforth as Robinson-Danforth Commission Company. Now it operates more than 50 feed mills in the United States, Canada, and Mexico.

Among the major flour millers in the feed business are Pillsbury Company, General Mills, International Milling Company, and King Midas. All market a substantial part of their flour milling by-products through the animal and poultry rations which they themselves produce and sell.

Fig. 97. Typical Feed Plant

Regional in scope, this feed plant manufactures rations which are sold over a three-state area.

Some 75 feed manufacturers are arbitrarily classified as "large." Each of these operates more than one plant and makes at least 100,000 tons of feed a year. Another group of 130 firms includes companies each producing 50,000 to 100,000 tons per year.

STATISTICS OF FEED PRODUCTION AND CONSUMPTION

Feed Production

Writing one of the first handbooks on grain and feed, Strowd (1925) forecast: "We may look for a bigger, better business in commercial feeds." He continued: "More by-products feed will be produced and less feed will be exported to meet the increased domestic demand."

Neither Strowd nor any other agricultural economist of those days dreamed of the fantastic crop yields in the United States today. But he accurately judged that increased use of roughages would not hurt the tonnage of grain used in feeds: "We are so far behind in applying the known principles of animal nutrition, that this offset [use of more legume hays] will hardly be felt even as a check on the increasing demand for commercial feeds."

True to these predictions, statistics from the American Feed Manufacturers Association and the United States Department of Agriculture

indicate that formula feed usage is growing year by year. Here are comparative figures for six different years:

1948	25,500,000 tons
1950	29,100,000 tons
1952	32,400,000 tons
1954	35,000,000 tons
1956	35,700,000 tons
1958	40,000,000 tons

As higher-energy rations are developed and new additives devised to make feeds more productive, the rate of increase of total production probably will be slowed below the growth rate indicated above.

Production Trends

As the American consumer has turned away from heavy cereal eating in his own diet in recent years he has, fortunately, insisted on more meat, milk, and eggs. The production of these protein foods has, in turn, helped to use up the available cereal grains.

The housewife is buying more broiler chickens than most poultrymen would have dreamed possible ten years ago. These heavy grain consumers, broilers, have become a major agricultural industry in a decade, with annual production above 1,500,000,000 birds.

Farmers are keeping an average of 300,000,000 laying hens year in and year out.

Dairy cows number about 20,000,000, with annual milk production some 128,000,000,000 lbs.

Beef cattle numbers fluctuate depending on market prices but are averaging 60,000,000 on hoof at any one time.

Sheep and lambs number 31,000,000 head.

Swine numbers rise and dip, but the spring crop average in recent years has been about 58,000,000 and the fall crop 38,000,000.

Turkey raisers are producing 81,000,000 marketed birds a year and keeping 3,500,000 breeding hens.

Roasting chickens and other poultry not listed above total 415,000,000 birds.

Feed Consumption

In the feeding year 1957–1958 (October 1 through September 30), available supplies of grains and low-protein by-products totaled 152,000,000 tons. Farmers actually fed 112,000,000 tons of this available supply.

Accurate figures on the previous feeding year indicate that feeds utilized 2,500,000,000 bushels of corn, 1,100,000,000 bushels of oats, 212,000,000 bushels of barley, 179,000,000 bushels of grain sorghums, and 2,000,000 tons of wheat and rye. The bushel figures on corn, oats, barley, and grain sorghums convert to about 97,000,000 tons.

Use by Types of Animals

Poultry are the largest consumers of commercially-manufactured feeds, and, as a result, of the cereal grains used by the feed industry. Of all the feed consumed by poultry, some 63 per cent is manufactured in feed mills. Other classes of livestock rank far behind. Less than seven per cent of all manufactured feed sold is consumed by beef cattle. Dairy cattle use only 20 per cent of total production. Hog farmers purchase less than one-tenth of the commercial feed output. In all of these fields, the feed industry has great opportunities to expand the use of its products.

Swine consume 47,503,000 tons of grain a year, according to the feed manufacturers' group. This is computed on the basis of each hog eating some 422 lbs. of grain to market weight.

Laying birds, which are not marketed until their usefulness as egg producers is finished, use some 11,220,000 tons of cereals a year. A chicken broiler (marketed at about nine weeks of age and at two-and-one-half to three pounds) eats some six pounds of grain. In a year, the broiler industry thus uses more than 4,000,000 tons of grain. Roasting chickens eat 17 lbs. of grain to market weight and collectively are fed 3,871,000 tons a year. Turkeys vary by breed types—light, medium, or heavy—but average 45 lbs. of grain per unit for a category consumption of 2,325,000 tons. Ducks, geese, and game birds consume 154,000 tons of grain a year.

Dairy animals use 21,100,000 tons of grain a year. Of this total, 17,700,000 tons is eaten by milk cows and 3,400,000 tons by bulls and heifers. Beef cattle, primarily range-fed, consume 15,400,000 tons of grain a year. Use of grain by sheep and lambs is 637,000 tons annually.

It is apparent from these figures that feed uses of cereal grains are extremely important in terms of total consumption of farm crops.

FEED PROCESSING METHODS

Processing of cereal grains and other ingredients into mixed feed in the feed mill itself is a comparatively simple operation. It consists of converting incoming grains and other products into the form and size desired in the finished feed, adding other ingredients and mixing them with the grains, then forming a finished feed in the shape or consistency desired for feeding.

The basic forms of finished feed are mash, pellets, and crumbles. The latter are pellets which have been formed and then crushed or broken. Some feeding of a liquid supplement based on ethanol, molasses, and urea is being done on a limited scale in ruminant feeding sections.

The first step in feed processing and production is unloading the incoming ingredients. Grain is usually received at the feed mill by truck, railroad, or boat. In some rare cases horse-drawn vehicles still bring it in. In the Great Lakes area, water transportation is popular for grain movement. Barges still transport grain down the Mississippi to Gulf cities and around to Florida.

Rail transport is important in the Plains states and the Middle West and to some extent in the East. Trucks have gained rapidly in grain hauling tonnage in recent years all over the country. This has been particularly true in sections where rail service tended to be slow or expensive.

Unloading and Conveying

When a shipment of grain is received at the feed mill, it is unloaded by gravity, by air, or by manual means. Drop-bottom rail cars sometimes are used. Trucks open their tail gates, are tilted, and drop their cargo into underground pits. Boats often are unloaded by air, either with a vacuum or a positive-air system. Shovels wielded by hand still are sometimes used in rail car and truck unloading and to clean out corners of compartments in all types of carriers.

Practically all feed mills depend on the gravity system for moving their ingredients through the actual processing operation. But first the grain must be elevated so that gravity may carry it through the processing machinery.

Conveyors to move the grain include screw-type units, sometimes made of stainless steel; belt conveyors; drag conveyors, which utilize single or double chains to haul grain along a stainless steel chute; air units, which carry grain along on a jet-like stream of forced air into which the grain is introduced.

The most widely used type of materials handling elevator is the continuous belt on which are mounted metal or plastic cups. These so-called "bucket" elevators will convey grain upwards hundreds of feet if necessary.

Storage and Drying

Grain is stored in concrete silos, wooden bins, or steel tanks. Efforts to store grain out-of-doors under canvas or plastic have not proved very successful because of the danger of rain and bird and rodent damage.

Usually moist grain is not accepted by the feed mill. If grain of high moisture content has been purchased, it will be dried before storing. Grain driers are housed in separate structures adjacent to the feed mill buildings and remove moisture from grain by heat-treating it. Gas and oil-fired burners are most commonly used. An occasional feed mill will dehydrate alfalfa or some other grass adjacent to its plant. This process of dehydration is done with a rotating cylinder, heated to several hundred degrees by gas or oil flames.

Grinding

The hammer mill is the most widely used grinding device (see Fig. 98). The grinding chamber consists of rows of loosely-mounted "swing" hammers or plates of hardened metal. These hammers pulverize the grain by striking it as they swing. The pulverized material is forced out of the mill chamber when it is ground finely enough to pass through the perforations in the screen which is a part of the mill. Several sizes of screen openings are used, depending on the fineness of the end product desired. Poultry feeds, for example, are finely ground; ruminant feeds are coarser.

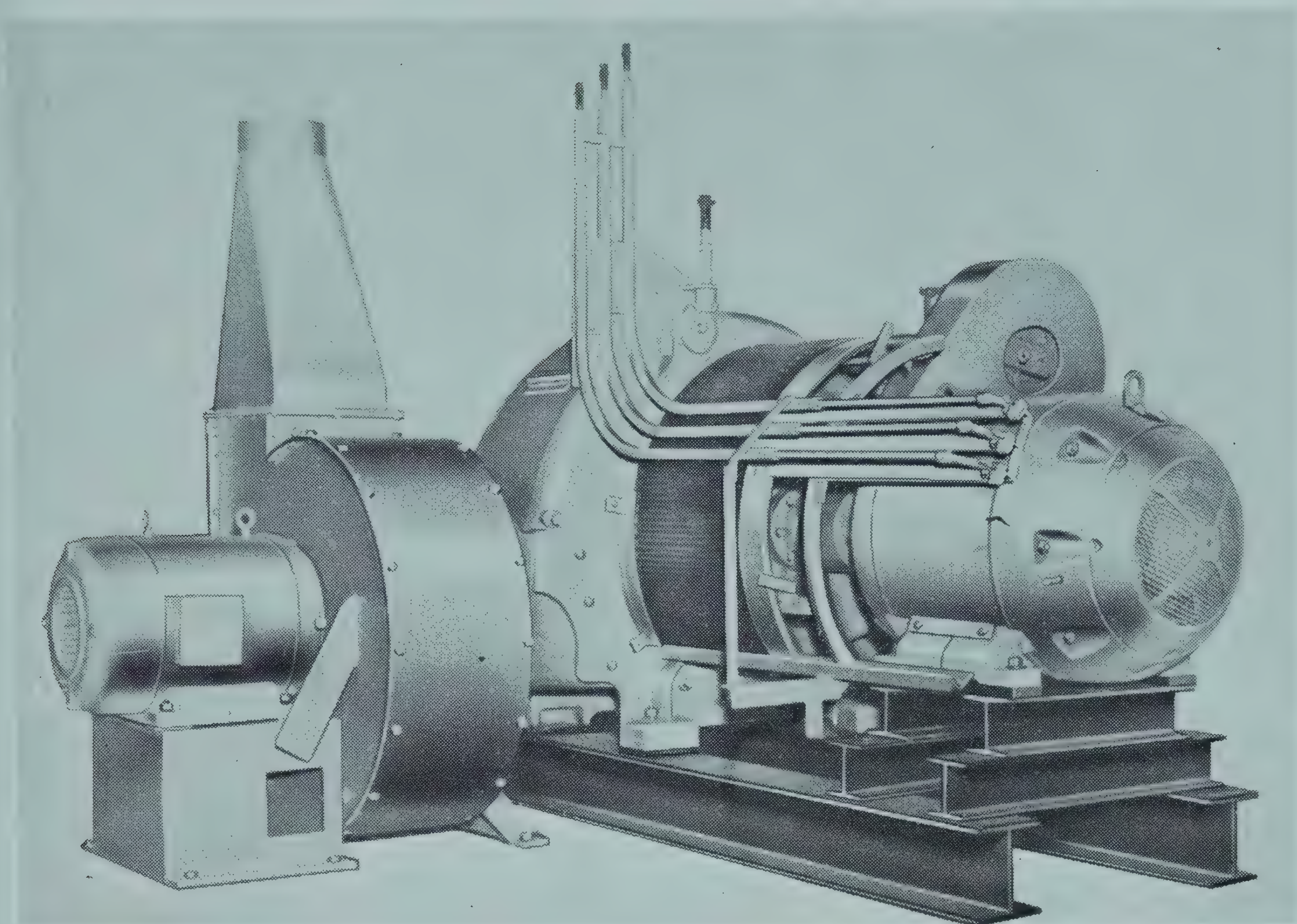
The attrition mill is used mainly on dairy and swine feeds where a fine-texture soft product is desired. Revolving grinding plates pulverize the grain. Roller mills include pairs of corrugated metal rolls, one member of which revolves at a speed two or three times that of other rolls. Grain is forced between the two rolls and sheared by the corrugations. Stone or buhr mills are obsolete in the feed business and exist only in a few places where a former flour mill turns out a small volume of feed.

In continuous-production lines, automatic feeders measure the amount of grain to be fed into the grinder so that it does not become overloaded. These feeders often measure on the basis of volume, although some commercial types weigh the grain they allow to pass into the grinder.

The grinder is the most expensive machine in the mill to operate from the power standpoint. To start and stop a hammer mill frequently is expensive. Thus the cost per ton to grind is less in the bigger continuous-production mills.

In small mills which custom mix to their customers' specifications, a power-measuring machine with a large clock-like face is sometimes used with success. The mill charges a certain fee per kilowatt of power used for the grinding operation. One such machine is the Grist-O-Meter, manufactured by Allied Industries, Inc., at Waupaca, Wisconsin.

Successful operation of a grinding unit such as a hammer mill requires



Courtesy of Prater Pulverizer Co.

FIG. 98. HAMMER MILL

Basic grain processing machine is the hammer mill, which drops free-mounted hard-metal bars against the grain.

a powered fan to convey away the ground material from the processing unit. The dusty feed mill is usually an inefficient production unit.

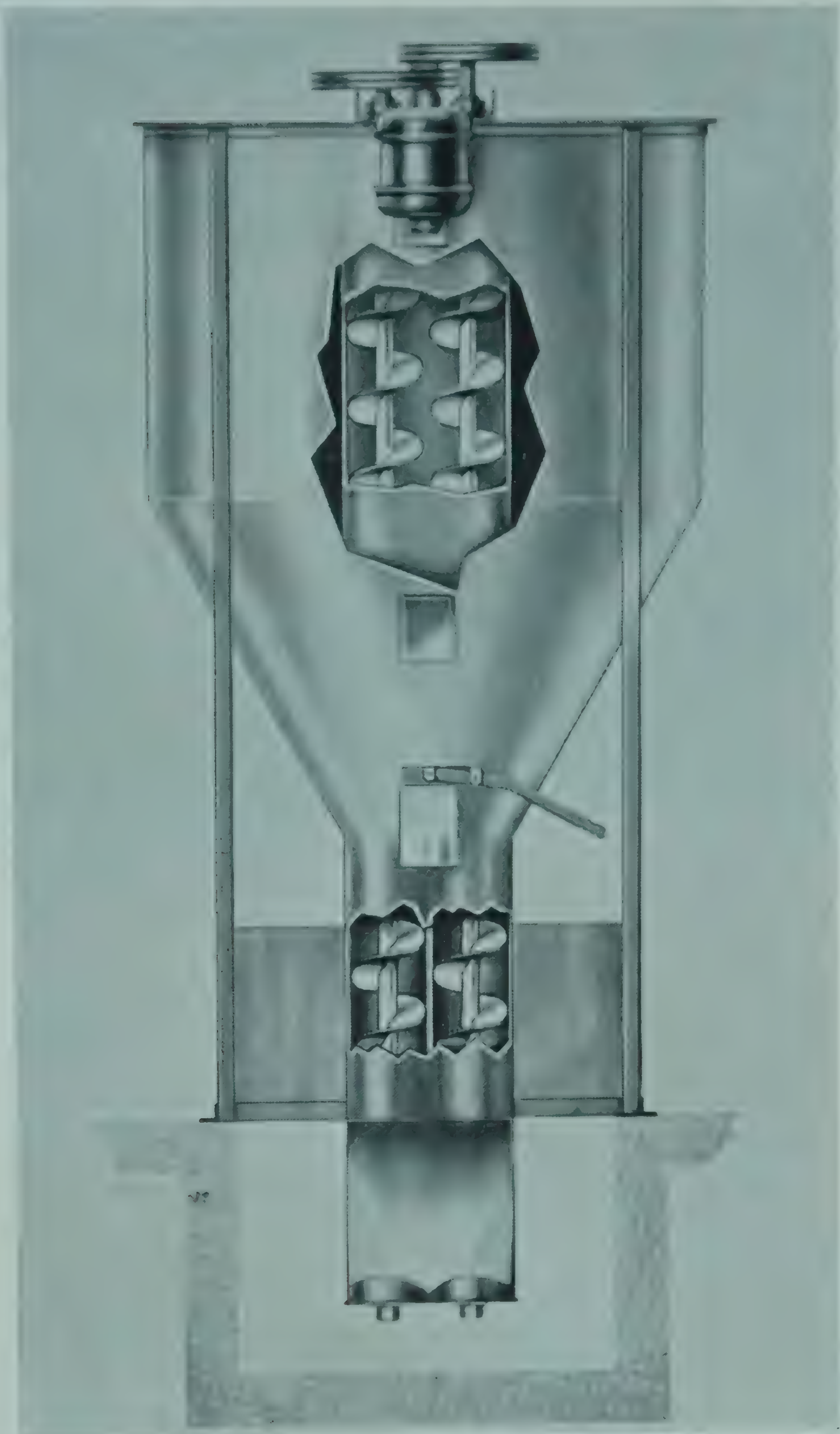
Scalpers and Separators

Cleaning equipment includes scalpers to remove coarse materials from the feed ingredients before they reach the mixer. Separators, which perform a similar function, often consist of reciprocating sieves which separate grains of different sizes and textures. Some mills employ these units to rough-grade grain as to quality and weight.

Magnets are essential in the feed processing line. Most mills install them ahead of the grinders and at other critical locations in the mill system. They remove tramp iron, bits of wire, and other foreign metallic matter which could harm the machinery and contaminate the finished feed. Both permanent and electric magnets are used.

Mixers

The basic procedure for making mash-type feeds is to measure into one end or the top of the mixing cylinder the grain which has been previ-



Courtesy of Prater Pulverizer Co.

FIG. 99. FEED MIXER

Most important feed processing unit is the mixer, which combines the ground grains with vitamins, antibiotics, drugs, and any other additives which go to make up the complete ration.

ously ground and add to it the vitamin concentrates, protein sources, drugs, and other ingredients. The paddles, ribbons, or screws inside the cylinder then are operated for the established cycle necessary to blend the various ingredients properly. The finished product is drawn off at the end opposite the loading entry.

In batch mixing, the mixer can be turned off once the cycle is completed. Batch mixers usually are vertical cylinders loaded at the top. In continuous production, a proportioned amount of ingredients enters one end and a comparable portion of finished feed emerges from the other end.

In the smaller plant, the vertical mixer is most popular. These units range in capacity from 500 lbs. to a full five tons. These figures are somewhat misleading because a ton of fine scratch feed can be mixed properly in a unit with only 50 cubic feet of capacity, while a ton of bulkier dairy feed would require 100 or more cubic feet.

The horizontal mixer is ideal for the larger feed mill which is in continuous production. An integral part of the continuous-production system is the percentage feeder, which measures the proportioned amounts of various ingredients going into the mixer. Some types measure by volume, others by weight. The latter appear to be more widely accepted.

A dry mash feed is ready for packaging in most cases after passing through the mixer. Other forms and types of rations require additional processing.

Molasses long has been a popular feed ingredient. It is somewhat hard to handle and to be added to dry feed must first be heated to a thinner consistency. This is done with a separate mixing unit, incorporating the heater. Dry feed and molasses are mixed in this unit. The mill making molasses feed should be able to store at least a railroad car of liquid molasses.

Fat blenders are a development of the middle 1950's. Since nutritionists have proved that added animal fat ups the rate of gain in poultry, manufacturers have begun adding extra fat to many formulas. Up to ten per cent fat is used in many poultry feeds. Fat is heated to a temperature above its melting point, perhaps as high as 170°F., and blended with the dry feed in a separate mixing chamber.

Pelleting

Pelleted-type feed is considered essential in feeding poultry, calves, rabbits, dogs, and fur-bearing animals. A major advantage claimed for pellets is that the animal or bird to which they are fed cannot separate the components of the ration to select those portions whose flavors it prefers. Instead, it must consume the entire portion of balanced feed in order to get the parts it prefers.

Pellets are made from feed which has been ground and mixed previously into mash form. If molasses or animal fat is to be added, these liquids are added to the dry mash just before it is to be pelleted. A

binding agent such as sodium bentonite aids in forming the pellets. Live steam is added to the dry material as it enters the openings in the circular dies which are the heart of the pellet mill. Water and heat in combination replace live steam in some pelleting processes. Dairy pellets frequently are "soft" because of their high molasses content.

After the pellets are formed and compressed, they are released from the dies into a conditioning unit. This often consists of a vertical or horizontal cooler which hardens the pellets. The feed then passes over a series of vibrating screens. Broken pellets and fines are separated from the perfect pellets and are recirculated into the mixing chambers to be reused. A cooling unit reduces the temperature of the pellets quickly and they are ready for packing or storage.

Pellet Reduction

Some animal feeds in pellet form are designed to be fed just as they come from the pellet mill. Others have to be reduced in size. The latter process is best known as "crumblizing." Actually, all it does is to break or cut the pellets to a smaller size.

Granulated feeds—the result of breaking pellets—are especially popular for young chicks, which can consume granules easier and more effectively than pellets. Baby chick size pellets cannot be made on a commercial basis because of their small size. This size encourages breakage and excess wear and tear on pellet mill dies, which would produce considerably less tonnage of the small pellets than they would of, for example, steer pellets. Yet the cost per hour of production would be identical.

Packaging

After the mash or pellet-type feeds are manufactured, they often pass over sifters before they are packaged or stored. These simple devices remove any extraneous matter, such as paper or string, which may have gotten into the finished feed.

As is the case with most consumer products, the package in which feed is sold is determined by the preferences of the buyers. This varies by geographical area, size of farming operation, type of livestock or poultry raised, and general economic conditions.

In the late 1950's, the large commercial livestock producer is buying bulk feed on an ever-increasing scale. This product is delivered to him by tank or box truck body and blown directly into his own feed storage tanks. The average bulk tank truck has room for 12 tons of feed—four tons each in three compartments. The most popular farm bulk storage tank holds approximately the contents of one of these compartments.

Multiwall paper sacks are gaining top popularity in feed packages. The 50-lb. paper bag of feed is available almost everywhere. Twenty-five and 80-lb. paper sacks also are used in some areas. Burlap sacks are popular especially in dairy and cattle feeding sections. They can be cleaned and reused and save packaging costs. Burlap sacks are usually

FIG. 100. TRUCK FOR BULK DELIVERY OF FEED

Large volume users of mixed feeds usually buy their requirements in bulk.

of the 100-lb. size. Cotton bags are especially popular for poultry feeds. Sizes from 25 to 100 lbs. are used. Dressprint sacks, which command a premium of about 40 cents over other cloth bags, are waning in popularity because of this assessment.

Metal pails are used for calf food and some other specialties. The 25-lb. size is used.

FEED CONSTITUENTS

Grains and cereal by-products are the bases of practically all complete feeds. What follows is a commodity by commodity description of the basic products and by-products as used in modern mixed rations for livestock and poultry.

Corn

The oldest type of dry feed still fed is based on corn. It is what is known in the industry and to the farmer as poultry "scratch" and is made

up of cracked corn, cracked wheat, cracked milo, steel-cut oat groats, and other ingredients.

As science demonstrated the superiority of all-mash feeding of young chicks, fine scratch feeds declined in popularity. But since 1955 there has been renewed interest in feeding a hard, finely-ground grain ration for the first 48 hours of the chick's life.

Here are some of the most popular forms of corn and its by-products used in feeds:

(1) Meal—finely-ground, unbolted corn.

(2) Cracked—which is also known as chop or ground, is ground, cut, or chopped kernels.

(3) Screened cracked—same as cracked but with the fine portions screened out.

(4) Feed meal—the fine portions referred to above.

(5) Ground ear—the entire ear except husk ground or cut.

(6) Ground ear including husk.

(7) Dehydrated plant—a new product consisting of the entire immature plant artificially dried and ground.

(8) Flaked—used primarily in pet foods, it is the cracked product run over flaking rolls, then dried and cooled.

(9) Toasted flakes—similar to the human breakfast product except they have no added sweetening or flavoring.

(10) Kibbled—steam-cooked cracked product expelled or extruded.

(11) Cobs—ground and including the ring cellulose.

(12) Hominy feed—mixture of bran, germ, and part of the starchy portion including not less than five per cent crude fat.

(13) Bran—outer covering of the kernel with little or no germ or starch.

(14) Germ cake—germ from which part of the oil has been pressed, with no other parts of the kernel.

(15) Germ meal—the cake, ground.

(16) Gluten feed—residue of shelled product after most of the starch, gluten, and germ have been removed by wet milling.

(17) Oil cake and flakes—germ from which most of the oil has been removed by extraction.

(18) Oil meal—same as above, ground.

(19) Sugar molasses—often called hydrol, it contains 43 per cent or more dextrose.

(20) Dried syrup—spray or roll-dried regular conversion syrup with not less than 42 per cent dextrose.

(21) Maltose processed—dried residue of ground product after starch is removed in making malt.

(22) Maltose processed gluten feed—dried residue from degermed product after starch has been removed in making malt syrup.

(23) Sweetened gluten—gluten feed combined with molasses or cane molasses.

(24) Distillers dried grains—dried portion of whole stillage retained by screens.

(25) Distillers dried solubles—condensed and dried screen stillage.

(26) Dried grains and solubles—a combination of above.

Summary of Corn Products.—Indian corn or maize is the most important feed grain in the United States. In recent years, over 3,000,000,000 bushels have been produced annually; almost all of this is used directly for feeding.

Oats

Oats long have been popular feeding materials. They supply an average of 12 per cent protein and $4^1/_2$ per cent fat, with about 11 per cent fiber.

Here are the principal oat products used in feeds:

(1) Pulverized—ground on hammer mill using fine screen.

(2) Ground—whole product ground fine or more coarsely on any type mill.

(3) Crimped—whole product lightly crushed or crushed flat; when flattened, it is usually after they have been steamed to avoid an excess of fine materials.

(4) Hulled—kernels produced from undried grain in the hulling process.

(5) Groats—kernels produced from cleaned and dried product in making meal.

(6) Meal—rolled groats or product containing not more than four per cent crude fiber.

(7) Hulls.

(8) Middlings—floury portion obtained in milling rolled product.

(9) Shorts—covering of the grain which lies immediately inside the hull and is fuzzy in texture.

(10) Mill by-product—hulls and groat particles from groat manufacture.

Rye

Although little rye is used in mixed feeds, these products sometimes are included:

(1) Bran—coarse outer covering of kernels.

(2) Feed—mainly mill-run of the outer covering of the kernel and germ with small parts of flour and aleurone.

(3) Red dog—aleurone with small portions of flour and bran.

(4) Low-grade feed flour—flour and small quantities of bran and aleurone.

(5) Middlings—feed and red dog combined.

(6) Flour middlings—feed, red dog, and flour combined.

Linseed

Although linseed is not a cereal, it is desirable to consider it in this section because it is handled like the cereals in feed processing.

The residual meals from linseed oil extraction long have been used for cattle and swine feeding. Some farmers feel that linseed meal puts a final "bloom" or finish on beef cattle which no other feed ingredient can do. This has not been explained, but it appears to be true.

These are the linseed and flax products which are fed:

(1) Oil cake—product obtained by removing most of the oil from flaxseed by extraction; the type of process must be specified—hydraulic, expeller, or solvent.

(2) Oil meal—finely-ground cake or flakes.

(3) Pellets.

(4) Flaxseed screenings oil feed—ground imperfect smaller flaxseed, weed seeds, and other foreign matter separated in cleaning flaxseed.

(5) Feed—product consisting of one or more oil meals mixed with flaxseed screenings oil feed.

(6) Flax plant product—leaves, corticle tissues, bolls, and broken and immature seeds which remain after harvesting seed and separating bast fibers and shives.

Wheat

When wheat is cheaper than corn, on a pound for pound basis, it is ground and used in feeds of many kinds. It is, of course, a valuable feed from the nutritional standpoint. These wheat products are commonly fed:

(1) Bran—coarse outer covering of the kernel.

(2) Middlings—fine particles of bran, germ, and flour plus some offal as milling by-products; maximum fiber 9.5 per cent.

(3) Brown shorts—similar to middlings but fiber maximum is 7.5 per cent.

(4) Gray shorts—similar to middlings but fiber maximum is six per cent.

(5) Red dog—offal plus some particles of bran, germ, and flour, with fiber top of four per cent.

(6) Feed flour—flour with fine particles of bran, germ, and offal; fiber limit 1.5 per cent.

(7) Mixed feed—coarse outer covering of kernel plus offal and fine particles of bran, germ, and flour.

(8) Germ meal—mainly used in dog and fur animal feeds, it is germ plus some bran and middlings or shorts.

(9) Germ oil cake—product resulting from removing oil from germ meal.

(10) Germ oil meal—above, ground.

(11) Flakes—product resulting from cooking, adding sugar and salt, and flaking and toasting whole product.

Rice

Rice milling by-products are used in poultry feeds and in other rations. They include:

(1) Meal—ground product with hull removed.

(2) Ground rough—includes hulls.

(3) Bran—pericarp of product.

(4) Huller bran—mostly bran and germ.

(5) Stone bran—siftings from materials resulting from removal of hulls; includes germs, hulls, broken product.

(6) Mill by-product—offal of product milling.

(7) Polishings—by-product of polishing kernels.

Barley

On the west coast, in particular, barley is in ample supply and often is used as the basic grain in feeds. It may be used in any economic amount Barley products which go into feeds are:

(1) Ground whole—entire product with no more than six per cent fiber or ten per cent weed seeds or other grains.

(2) Mixed feed—offal from milling flour from clean grain.

(3) Feed—by-product of manufacture of pearl product from clean product.

(4) Hulls—outer coverings.

(5) Dried malt sprouts—in widest use, they are a brewery by-product and contain 26 per cent protein.

(6) Brewers dried grains—dried extracted residue of product malt, which may be mixed with other cereal grains or products resulting from wort manufacture.

Grain Sorghums

The sorghum grains—including milo, kafir, and feterita—are gaining in importance every year as feed ingredients. In years past, there was little use of these products except in scratch feed. Now starch is being produced from sorghums and the resulting by-products are being fed. Here are some of the grain sorghum products used in feeds:

(1) Chop—entire product of the ground grain.

(2) Head chop—entire head, including grain and stems.

(3) Head stems—stems with grain removed.

(4) Mill feed—mixture of bran, germ, and part of the starchy portion of the grain.

(5) Feed meal—fine siftings from rolled or flaked processing of the product.

(6) Rolled—whole product run over smooth flaking rolls and then cooled and dried.

(7) Gluten feed—remaining product after most of the starch and germ have been removed in wet milling.

(8) Gluten meal—remaining product after most of the starch and germ have been removed and the bran separated in wet milling.

(9) Oil cake—germ from which part of the oil has been pressed in wet milling.

(10) Grits—flinty portions with little or no bran or germ.

Special Products

Practically every cereal grain has been fed at one time or another in some type of livestock or poultry feed mixture. The amounts have varied and also the purposes for which the grains were used. The preceding descriptions of grain products and by-products used in modern-day feed manufacturing is intended to cover those grains in most general use.

Dried cereal grasses are now being fed on an experimental basis, although their commercial use has not been established. These include early-cut wheat, oats, and rye which have been grown on fertilizer-enriched soil. The young plants are dehydrated at once—often right in the field—to protect their nutritive values.

Crumbs from breakfast food manufacturing production lines are used in fur animal feeds. These are tiny portions of wheat and corn flakes. Flaked cereals are also made as primary products. These are based on corn, wheat, barley, and other grains and are designed for use in dog foods and fur feeds.

WHICH INGREDIENTS TO USE

The feed formulator usually can choose from several grains to fill a certain requirement in the mixture he is composing. He should, however, consider not only the economic advantages to his company of using one ingredient rather than another, but primarily what the ingredient will contribute to the finished product in terms of the production of either meat, milk, or eggs by the animal unit to which it is fed.

Deyoe and Krider (1952) point out that a good ration is adapted to the age and individuality of the animal, and to the purpose for which it is being fed, it includes a variety of ingredients, and is palatable and safe. Furthermore, it should be economical and not produce an inferior end product.

QUALITY OF INGREDIENTS

Importance of Quality

A feed will stand up in competition only so long as it gives the farmer the performance he feels he has a right to expect of it, in terms of economic return.

Many farmers still try to buy "cheap" and then to doctor up the grain mixture into a balanced ration. This is folly, points out Titus (1955). He stresses:

"Wheat, corn, barley, oats, rye, and the grain sorghums, when shipped in interstate commerce, must be inspected and graded according to the official grain standards of the United States. In buying grain for the feeding of chickens, poultrymen and feed manufacturers should take advantage of this fact and buy according to grade. It is not sufficient to ask for just corn, oats, or any other grain for which standards have been established; the grade should be specified in order to obtain the quality desired."

Two prominent poultry scientists, Marsden and Martin (1955) make a similar point:

> "The best 'tonic' is a well-balanced diet. Money spent for tonics would be better spent providing a complete diet. Most condiments are of the 'shotgun' type; they have small amounts of many different minerals and other nutrients. Their apparent success in some cases may be due to the fact that the one essential element lacking in the diet was provided in the tonic. However, this method of approach is unscientific, expensive, and unsatisfactory."

Swine authorities Deyoe and Krider (1952) recommend quality grains and other components of hog feeds for best results. Hogs, they say, "are often called mortgage lifters because they provide a dependable and

regular source of income to a large number of farmers." But they note that the hogs won't lift mortgages unless they are fed properly.

REGULATION OF THE FEED INDUSTRY

The manufactured feed industry is supervised by state governmental agencies. Each state designates a "feed control official," although frequently he does not use that title. He may be the state chemist or simply an untitled staff member of the state department of agriculture.

It is his responsibility to insure that the mixed feeds which are sold in his state conform to the legal minima and maxima for fat, fiber, and protein and also that they live up to the claims printed on the tag which is affixed to each sack or delivered with each bulk order (see Fig. 101).

Many years ago, the feed control officials of the various states began to meet together to talk over their common problems. Out of these gatherings came the Association of American Feed Control Officials, an organization of the representatives of the various states who work together in the interests of standardizing regulations in the various states and in establishing clearly-worded definitions which explain in as simple terms as possible what is meant by, for example, "cracked corn." According to the Association (Bopst 1957), the 1958 definition of this product is:

"Corn chop, ground corn, or cracked corn is the entire product made by grinding, cutting, or chopping the grains of sound Indian corn, and may be fine, medium, or coarse. It must contain not more than four per cent of foreign material."

This definition has stood since 1931, but a committee reviews it and several hundred other definitions every year to make certain it is still accurate. Today the feed control official must also analyze and describe drugs, antibiotics, hormones, and other products which go into feeds. Then he can relax and check the grain content, a comparatively simple task.

Violation of proper labeling of feeds or failure to live up to label guarantees is punishable by heavy fines in all states. But serious violations are few and far between and most offenses are minor and unintentional.

F. D. Brock of the State of Texas wrote in 1957:

"Regulation by consent is nowhere better exemplified in the annals of law enforcement than by the cordial relationship existing between control officials and feed manufacturers. This situation was the result of continued effort to that end by the founders of the Association of American Feed Control Officials and forward-thinking members of the feed manufacturing industry."

100 LBS. NET WEIGHT

BLUE BIRD

CHICK STARTER

MEDICATED

For prevention of coccidiosis. Feed continuously as the only ration.

Active Drug Ingredient(s)

Nitrophenide 0.0125%

Guaranteed Analysis

Crude Protein, not less than	20%
Crude Fat, not less than	4%
Crude Fiber, not more than	3%
Nitrogen Free Extract, not less than	55%

INGREDIENTS

Corn Gluten Meal, Ground Yellow Corn, Dehulled Soybean Oil Meal, Fish Meal, Condensed Fish Solubles, Soybean Lecithin, Vitamin B-12 and Antibiotic Feed Supplement, Vitamin A Feeding Oil, Calcium Pantothenate, Niacin, Choline Chloride, Menadione, Riboflavin Supplement, D-activated Animal Sterol, Butylated Hydroxy Toluene (BHT) (a preservative), Animal Fat (preserved with propylene glycol, butylated hydroxyanisole, propyl gallate and citric acid), Limestone, Defluorinated Phosphate, Salt, Potassium Iodide, Iron Oxide.

Manufactured by

BLUE BIRD FEED MILLS

Robin, Indiana

Feeding Directions on Reverse Side

Fig. 101. Type of Label Required by Feed Control Laws

Laws vary slightly from state to state. Almost all require that a tag be affixed to each bag of feed or submitted to the farmer with each bulk delivery. This is a typical feed tag, showing the grains in the mixture as well as other ingredients.

Taking Samples

The Association of Official Agricultural Chemists (Anon. 1958) uses this as its official procedure for drawing off samples of commercial feeds for inspection:

Use slotted single or double tube and rod, all with pointed ends.

Take at least 1 lb. sample, 2 lb. preferred, as follows: Lay bag horizontally and remove core diagonally from end to end. Determine number of cores as follows: From lots of 1–10 bags, sample all bags; from lots of 11–20 bags, sample 10 bags; from lots of 21–40 bags, sample 15 bags; from lots of 41 or more bags, sample 20 bags. Take 1 core from each bag sampled, except that for lots of 1–4 bags take enough diagonal cores from each bag to total at least 5 cores. For bulk feed draw at least 20 cores from different regions; in sampling small containers (10 lbs. or less) 1 package is sufficient. Reduce composite sample to quantity required, preferably by riffling, or by mixing thoroughly on clean oilcloth or paper and quartering. Place sample in air-tight container.

Grind sample to pass through sieve with circular openings $^{1}/_{25}$ in. (1 mm) in diameter and mix thoroughly. If sample cannot be ground, reduce to as fine a condition as possible.

PET FOODS

Although to the layman observer it might seem as if canned dog and cat foods have just about wiped out dry rations, such is far from the case. Instead, the sales volume of dry pet foods increased 60 per cent from 1952 to 1957, according to the federal Census Bureau. During the same period, the consumption of canned dog and cat foods rose by some 40 per cent.

Dry pet food consumption in 1957 totaled better than 718,000 tons. Practically all kinds of cereals go into pet foods. Here are some of the ingredients of leading pet foods on the market today:

(1) corn gluten meal; (2) cooked corn grits; (3) soybean meal; (4) alfalfa meal; (5) brewers grains; (6) distillers grains and solubles; and (7) wheat germ oil.

Dog foods, of course, are the biggest sellers in the pet ration category. They account for nearly 80 per cent of all pet food sales. Ranking second are cat foods, at about eight per cent of the total. Bird food counts for another five per cent. Aquarium supplies make up most of the remaining seven per cent of total pet food sales.

Forms of the Product

Dry cereal-type dog and cat foods are marketed in several forms. Working dogs—including farm dogs—are most likely to be fed cubed, pelleted, or crumblized food.

Ribbon-type dog food has been marketed successfully by a breakfast

cereal manufacturer for many years. Some manufacturers produce a coarse mash designed for wet-feeding to dogs. This product is mixed with water, milk, or gravy to enhance its palatability to the animal.

A high-priced dry pet food may be marketed as a "treat" or "candy" to reward dogs and cats for good behavior or good performance. This usually is an identical product to the less expensive pellets or cubes, but may offer a variety of colored pieces, sometimes of different shapes, in a small package, usually about six ounces, selling for from 19 to 39 cents.

A tremendous market success has been scored by a St. Louis dog food manufacturer with a new form of dog food. This product is marketed in an irregular-shaped piece and is specially flavored. Both pet and working dogs took to the new product on its inception and the company is guarding its formula and production method zealously.

No Longer By-Products.—In the early days of the pet food business, dog and cat foods were thought of primarily as avenues for disposal of by-products of the primary activity and product of the company. Such is not the case today.

Among the prominent concerns which manufacture dry dog food as a basic product are these: Carnation Company, Ralston Purina Company, General Foods Corporation, and Quaker Oats Company. These four firms spend thousands of dollars a year in improving the formulation and production processes for their dog food. Ralston Purina Company, for example, carries on a continuing experimental feeding program with dogs at its research farm at Gray Summit, Missouri.

Consumer Preferences

For many years, the consumer appeared to be shifting in preference from cereal type to canned dog foods. Ease in feeding and apparent popularity with the dog gave added impetus to canned foods. However, farm dogs traditionally ate table scraps plus cereal-type dog food purchased along with farm animal feed from the local feed mill. The farmer's preference in dog food continued to be the dry product in big bags—sometimes holding 100 lbs. each, if he had three or four dogs. A declining supply of horse meat plus general inflationary trends in the economy appeared to affect the price of canned dog food more than dry. As a result, the dry food makers began to make inroads in the pet-dog market, thanks to improved flavoring of their products and to more effective stressing of economy and balanced diets in their advertising.

Most dry dog food makers add packing house by-products—particularly meat scraps and blood products—to the cereals and vitamin concentrates they use. In addition, some proclaim that they use natural or artificial sources of chlorophyll to help reduce the dog's natural body odor. A few

years ago the producer of such a chlorophyll product used a herd of goats to test-run the chlorophyll product he ultimately marketed for use in dog foods.

Returned, unsold bakery products also are important components of some brands of dog food. Popular for these products are dry bread, cake, cookies, and stale ice cream cones.

All dog and cat foods are cooked, usually under steam pressure. Dry dog foods are packaged most commonly in two-and-one-half-pound cartons for grocery and supermarket trade, and in 5-lb., 10-lb., and 25-lb. multiwall paper bags for sale through feed outlets, sporting goods stores, veterinarians, and kennels.

FUTURE OF GRAINS IN FEEDS

Improved formulas for manufactured feeds include minute quantities of drugs and other products which increase the "feed conversion" efficiency of the animal or bird. This enables the animal unit to do more with every pound of feed it eats.

These improvements are cutting down on the amount of grain required per animal unit. But changes in eating preferences of the American public towards more protein foods require greater production of meat, milk, and eggs. Thus the total requirement for grain should continue to increase, although the amount consumed by each animal unit declines.

Cereal is a well-established base of the mixed feed product. It should continue to perform this role in the future.

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Ernest B. Kester

Rice Processing

INTRODUCTION

The belief is widespread that rice is of major importance as a crop only in countries where its consumption is high and where it is the basic energy food for the inhabitants. Few realize that in a list of 84 domestic crops, rice ranks 13th in dollar value. Our annual production of rice is from 2 to 2.5 million tons. The total represents, however, only about one per cent of the world total, and we eat less than half of what we raise. Our consumption is 5 to 6 lbs of rice per person a year. This figure seems small in comparison with the 200 to 500 lbs. per capita consumed in some Asiatic countries, but the fact that it remains at this level is significant, when we consider that starchy foods in our daily meals are on the decline. People who take the trouble to cook rice properly like it exceedingly well and find that its bland pleasing flavor allows it to blend readily with meats, fish, fruits, vegetables, and dairy products into tasty dishes.

Although varieties of rice grown in different lands number into the thousands, the United States raises only 13 or 14 in major quantities. Long-grain varieties are Rexoro, Bluebonnet, Sunbonnet, Texas Patna, Century Patna, and Toro; in the medium-grain group are Zenith, Magnolia, Calrose, Nato, and Arkrose; the common short-grain rices are Caloro and Colusa. One short-grain variety is a special type of rice sometimes called glutinous or waxy rice. It is raised in small quantities in California and is consumed for the most part as a ceremonial food by first generation Japanese.

About 75 to 80 per cent of the domestic rice production is in the South, principally in Arkansas, Louisiana, Mississippi, and Texas, and to a lesser degree in Florida, Missouri, South Carolina, Tennessee, and Arizona; the remainder is raised almost exclusively in California. Soil and climatic conditions of the South are favorable to growth of long- and medium-grain rice varieties which are preferred by American consumers. The West grows mostly short-grain varieties but also raises Calrose in the medium-grain group. Attempts to grow long-grain rices in the West have not been successful. Somewhat more than half of the domestic rice crop

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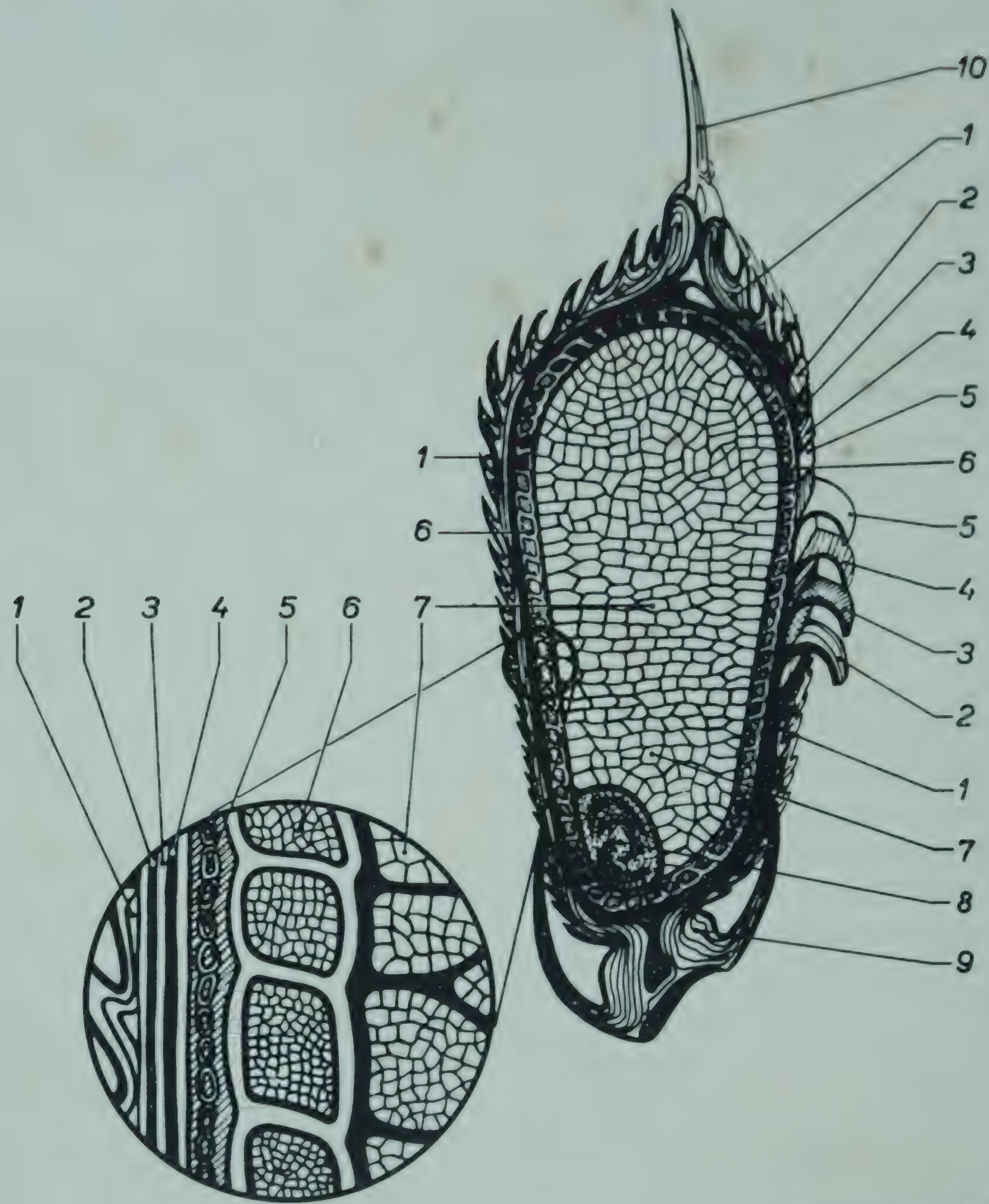


Courtesy of FAO

Fig. 102. Structure of the Rice Kernel

1. Hull (glume and palea); 2. Epicarp; 3. Mesocarp; 4. Cross layer; 5. Testa; 6. Aleurone layer; 7. Starchy endosperm; 8. Embryo; 9. Non-flowering glumes; 10. Apex or beard.

and about 85 to 90 per cent of the California crop is sold in off-shore markets.

Fig. 102 represents a grain of rice as it exists on the panicle of a rice plant when ready for harvest. Threshing with a combine separates the grains from each other and yields what is known as rough rice or paddy. Each grain is encased by an easily removed, protective hull. Inside the hull is a kernel of brown rice, so-called because of the dark bran layers or

pericarp covering the endosperm. In a depression at the end of the grain is the germ. Underneath the bran coating is a layer of protein-rich cells called the aleurone layer.

Rice is milled to remove bran, germ, and the aleurone layer. The coarse, outer bran coatings, the germ and small bits of endosperm constitute the rice bran of commerce. The white inner bran and the aleurone layers are removed in the final stages of milling and together comprise the fraction known as rice polish. White rice is the final product. It is usually most valuable when perfectly white, admixed with a minimum quantity of broken kernels, and free of weed seeds, damaged kernels, and other objectionable material. It is high in starch, is an excellent high-energy food, but is low in those life- and health-giving elements known as the vitamins.

Rough rice yields approximately 20 per cent of hulls, 8 per cent of bran, 2 per cent of polish, and 70 per cent of milled rice. Although raw white rice is the commonest form of rice sold and used by many consumers throughout the world, various practices have come into being for improving rice as a convenience item, for increasing its nutritional value and for giving it improved cooking and processing characteristics. In subsequent parts of this chapter will be discussed in detail the milling of rice and processes for parboiling, enriching, canning, and converting it into quick-cooking forms.

The vitreous long-grain rices are preferred in the domestic market for cooking and processing into canned formulations such as soups. The softer short-grain or Pearl types are sold to some extent for home use but are raised mainly to supply trade requirements in off-shore markets. They are used exclusively for making puffed rice. Both types may be manufactured into other dry breakfast cereals and both are used in parboiling operations about which more will be said later. The short-grain varieties are not so easily cooked without becoming cohesive as are the long-grain rices, but this disadvantage is overcome for the most part when precooked rice is canned or made into dry quick-cooking rice products. In some instances, the soft characteristics of short-grain rice are an advantage. For example, the brewing industry, which uses broken grades of rice as a source of carbohydrates, prefers short-grain types because they disperse more readily in the kettles.

The difference in behavior of long-and short-grain rices appears to lie in the composition of the starch fraction which constitutes about 90 per cent of milled rice on the dry basis. The starch of long-grain rice may contain as much as 23 to 25 per cent of amylose, whereas in short-grain rices, amylose may be 14 per cent or lower (Williams *et al.* 1958). The so-called glutinous rice contains virtually no amylose.

Rao *et al.* (1952) determined the weight of water imbibed at 208° F. by 100 gm. of rice (swelling number) of different varieties and found that it bore a direct and linear relationship to the per cent of amylose in the samples.

TABLE 81

COMPOSITION OF RICE AND RICE PRODUCTS[1]

	Brown Rice	Rice Bran	Rice Polish	Milled Rice	Parboiled Rice
Carbohydrates, per cent[2]	87.2	46.6	66.8	91.5	...
Protein, per cent[2]	8.3	14.6	13.2	7.6	...
Fat, per cent[2]	2.0	13.4	10.7	0.3	...
B-Vitamins, μg./gm.					
Thiamin	4.2	27.9	23.9	0.80	2.57
Niacin	47.2	408.6	384.7	18.1	39.8
Pyridoxin	10.3	32.1	30.8	4.5	...
Pantothenic acid	17.0	71.3	92.5	6.4	...
Riboflavin	0.53	2.68, 1.77[3]	1.34	0.26	0.36

[1] Carbohydrate, protein, and fat figures are taken or calculated from data of Yampolsky (1944); carbohydrates for bran and polish are the percentage of nitrogen-free extract. All vitamin values under Brown rice, Rice bran, Rice polish, and Milled rice, except those for riboflavin, are averages for samples of three varieties (Blue Rose, Fortuna, and Early Prolific) (Williams *et al.* 1953). All values for riboflavin (except under Parboiled rice) are averages of 7 samples (2 Supreme Blue Rose, 2 Early Prolific, 1 Fortuna, 1 Lady Wright, and 1 Improved Blue Rose) (Kik and Van Landingham 1943). All vitamin values under Parboiled rice are averages of 6 samples of "Converted Rice" (Kik and Van Landingham 1943A).

[2] On moisture-free basis.

[3] First and second break brans, respectively.

Table 81 includes representative analyses showing the composition of rice and rice products. By comparing figures, it is seen how rice loses nutrients when it is milled and how excessive losses of these substances can be prevented by parboiling.

The controlled enrichment of white rice, which is described in another part of this chapter, consists in adding nutrients in such amounts that the final product is about the equivalent of brown rice in thiamin, niacin, and iron content.

In rice breeding programs, geneticists now consider cooking and processing behavior as important criteria of a selection's suitability for specific purposes. Formerly, rice was judged solely on the basis of its field and milling characteristics. When Century Patna was released in 1951, it proved to be nontypical of long-grain rices, and was not so acceptable as other long grains for certain types of processing. At the Rice-Pasture Experiment Station, Beaumont, Texas, a Rice Quality Laboratory was established in 1956 for the purpose of performing specific chemical and physical tests which, collectively, indicate how a specimen of rice will behave in contact with water at gelatinizing temperatures. Results of these tests serve as guides for the plant breeders in choosing selections for release or further development.

The value of this type of analysis has already been conclusively demonstrated. Tests which serve to differentiate cooking qualities of a rice are its gelatinizing and pasting characteristics (Halick and Kelly 1959), its water-absorbing properties at different temperatures, (Halick and Kelly 1959; Batcher *et al.* 1956) the starch-iodine blue test (Halick and Keneaster 1958) the type and extent of disintegration of whole kernels in contact with dilute alkali (Little *et al.* 1958) and the amylose:amylopectin ratio (Williams *et al.* 1958). Batcher *et al.* (1958) have evaluated subjectively the palatability of 26 varieties of rice and found a correlation between the cohesiveness scores for cooked samples with water uptake and total solids in the residual cooking liquid.

TABLE 82

PER CENT OF NITROGEN AND THE MORE IMPORTANT AMINO ACIDS IN RICE AND RICE PRODUCTS[1]

	Brown Rice	Rice Bran	Rice Polish	Milled Rice	Parboiled Rice
Nitrogen	1.23	2.14	1.98	1.02	1.15
Cystine	0.090	0.137	0.141	0.073	0.13
Methionine	0.23	0.34	0.43	0.21	0.15
Tryptophane	0.074	0.096	0.107	0.086	0.08
Lysine	0.260	0.443	0.444	0.280	0.26
Arginine	0.254	0.344	0.273	0.251	0.41
Histidine	0.054	0.090	0.071	0.059	0.14
Threonine	0.27	0.37	0.39	0.30	0.28
Valine	0.50	0.61	0.63	0.49	0.41
Leucines	0.90	1.18	1.22	0.93	0.81
Phenylalanine	0.31	0.44	0.48	0.39	0.31

[1] Percentages of nitrogen, cystine, tryptophane, lysine, arginine, and histidine under Brown rice, Rice bran, and Rice polish were determined on Supreme Blue Rose variety (Kik 1942). Percentages of methionine, threonine, valine, leucines, and phenylalanine under Brown rice were determined on a commercial sample (Kik 1956A), under Rice bran and Rice polish, on commercial samples (Kik 1956), under Milled rice on an unidentified sample (Kik 1954). All analyses under Parboiled rice were determined on a sample of "Converted Rice" (Edwards and Allen 1958).

All of these tests reflect the composition, reactions, and histology of the starchy part of the rice kernel. They do not, however, measure adequately that elusive quality of texture or "mouth appeal" of cooked rice. It remains for someone to develop an instrument or method for measuring the combined qualities of cohesiveness, "chewiness," and smoothness, which are the important elements in sensory evaluation of a bland, cooked product such as rice.

The cooking and processing behavior of rice improves with storage; that is, the cooked texture of old rice is considered preferable by most people to that of freshly harvested rice. Sreenivasan and Giri (1939), in a study of rice quality changes after harvest, observed that increased temperature and reduced air supply during storage quickly improves the cooking quality of rice whereas paddy stored cold did not improve much

after several months. Well stored rice grains were found to swell on cooking to about four times their original volume, whereas freshly harvested rice scarcely swelled to double its size with similar treatment. These authors further concluded from their observations that fresh rice contains an active amylase which causes it to become pasty on cooking but is inactivated upon storage. Desikachar (1956) reached similar conclusions—found that fresh rice not only showed a greater tendency to become pasty but also lost more solids into the cooking water than did stored rice. Moreover, its capacity to imbibe water was greater and the capacity of its amylose to bind iodine was lower.

After the starches, the next most important chemical constituent of rice is the protein, comprising 5 to 10 per cent of the milled grain. It is largely glutelin, and its influence on cooking properties of rice has not been determined.

In localities where rice is a major food item, the quality of its protein becomes an important consideration. Seventeen amino acids have been identified in rice protein (Kik 1956A), including all the recognized essential amino acids (Table 82), but how rice proteins differ from each other in chemical composition, structure, or physical behavior has not been investigated to any great extent.

Sasaoka (1957) has stated that the glutelin of glutinous (waxy) rice differs from that of ordinary rice glutelin in its higher content of tyrosine, lysine, and histidine, and lower amounts of other amino acids. Another point of difference is that glutinous rice contains no combined nucleic acid in its glutelin fraction .

Sure (1953), in a study of protein supplementation, found that when one-half of the protein in milled wheat was replaced by an equivalent amount of milled rice protein in rat feeding tests, a 114 per cent increase in growth and an 86 per cent increase in protein efficiency resulted. A similar replacement of corn with rice gave even more striking results, producing a 236 per cent increase in body weight and a 165 per cent increase in protein efficiency. The author concluded: "For people of low income levels, who use largely corn for their basic cereal foods, . . . it would seem most desirable to grow more rice under favorable soil and climatic conditions and consume a greater proportion of rice to balance the proteins in corn, which are deficient in a number of amino acids but particularly in lysine, tryptophane, threonine, and methionine."

Other nutrition studies of essential amino acids bring out complex relationships. According to Rosenberg and Culik (1957) when rats were fed a basal diet of 90 per cent milled rice containing 0.05 or 0.1 per cent added lysine, they showed an increased growth rate in five weeks over the

control animals, but that if the lysine content was raised to 0.2 per cent or more, much of the growth rate response was lost. They concluded that "high levels of lysine overbalance the amino acid pattern." Their findings agree with those of Pecora and Hundley (1951), who discovered an apparent interrelationship between lysine and threonine in promoting growth response.

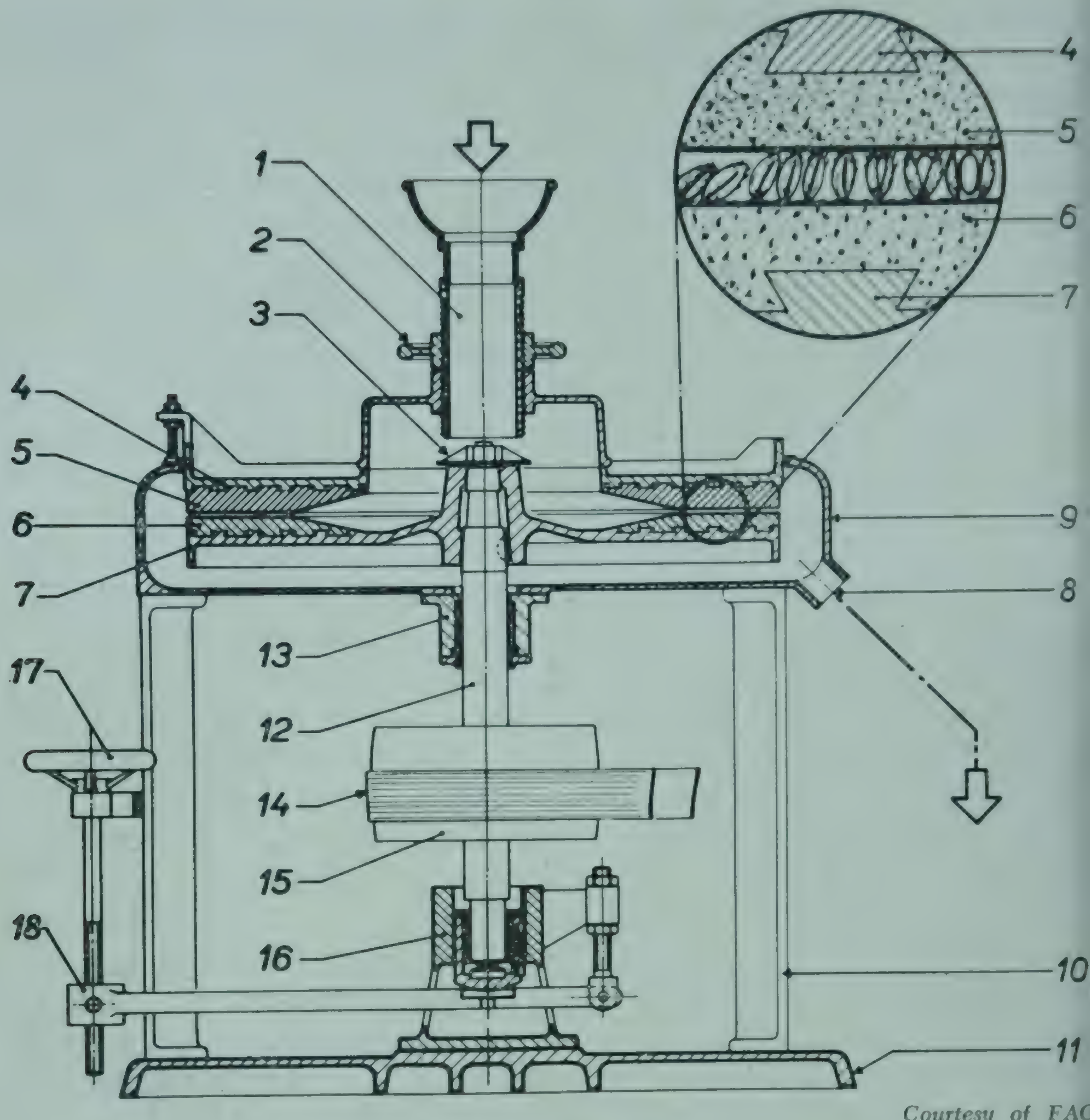
Other constituents present in rice, to a lesser degree, are sugars, hemicellulose, mineral matter, fiber, fat, free amino acids, short-chain plant acids, compounds of phosphorus (particularly esters of inositol and phosphoric acid), vitamin B constituents (Table 81), enzymes and pigments. Some of these, such as the fat, have an important bearing on the storageability of rice and its processed products and, in this connection, will be discussed later in this chapter. The fat occurs largely in the bran and germ and is easily recovered and refined to a high grade stable vegetable oil. The hemicelluloses may be partly responsible for adhesion of the bran to the endosperm and, therefore, a factor in the milling of rice. Phytin is the principal phosphorus compound in rice. It is reported to comprise more than eight per cent of the bran fraction (La Pierre 1955). Rice ash contains calcium, iron, potassium, magnesium, sulfur, and phosphorus, as well as minor amounts of other elements. Like the corresponding mineral constituents of other foods, these are important nutritional factors.[1]

RICE MILLING

A rice mill is an elaborate assembly of devices for handling the rough grain as it comes from the warehouse end, with a minimum of manual labor, turning it into finished white rice, sacked and ready to market. All operations are mechanically performed, including transfer of the rice from one machine to another for the next operation. Excellent descriptions of rice milling and processing equipment have been published by the Food and Agriculture Organization of the United Nations (Aten and Faunce 1953; Borasio and Gariboldi 1957).

Equipment for milling rice is fairly well standardized in the United States. Rough rice is delivered to the mill from the drier or warehouse, usually admixed with various kinds of debris, such as straw, loose hulls, bran, weed seeds, pebbles, and granules of dirt. It also contains some broken rice. It must first be cleaned with shaker screens to remove small and large heavy impurities and aspirated to get rid of hulls and other chaff. The cleaned rice is then dehulled in a shelling device. This may be one of several types but most commonly used is the stone sheller (Fig.

[1] For a more complete discussion of the composition of rice and the products of rice milling, the reader is referred to McCall *et al.* (1951).



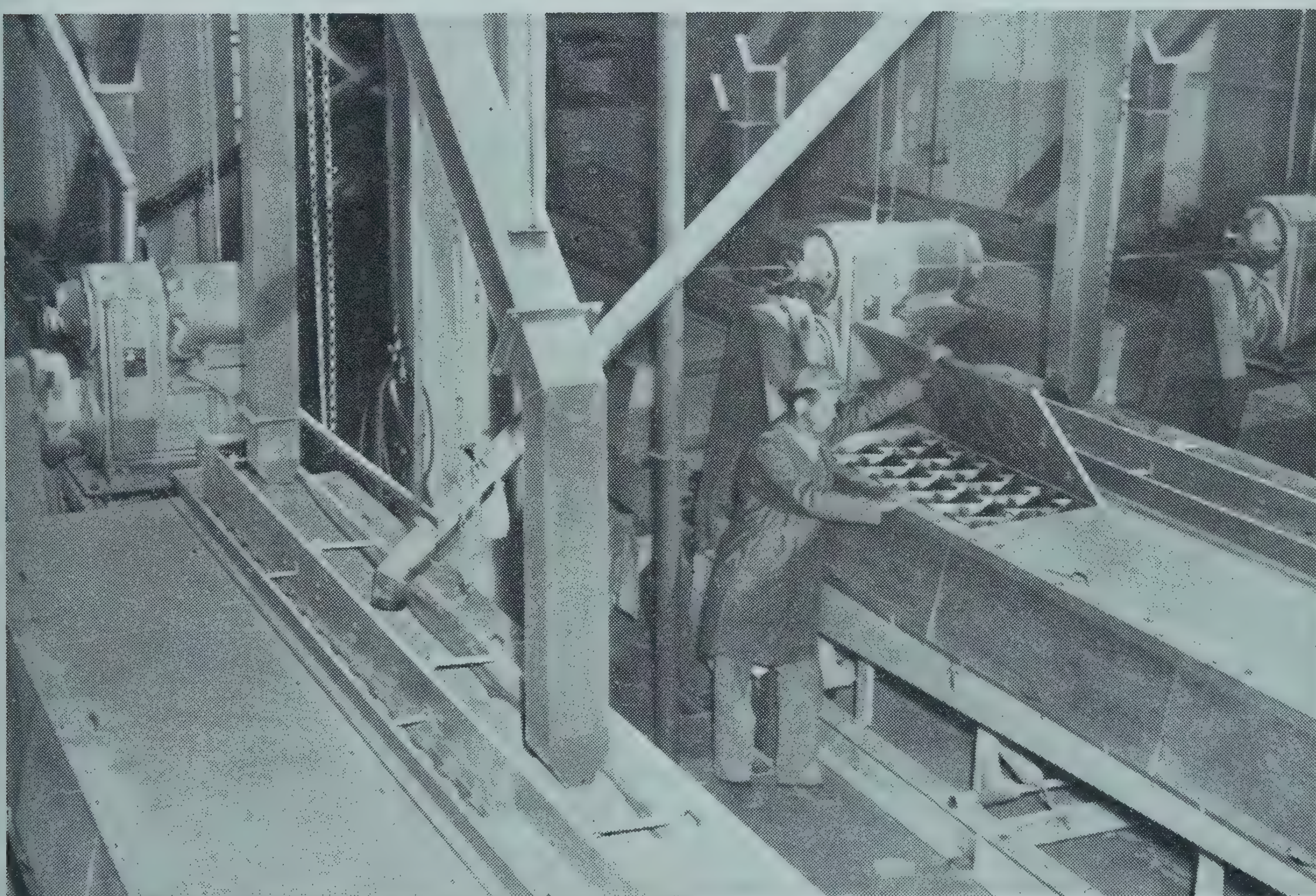
Courtesy of FAO

FIG. 103. STONE SHELLER

1. Feed hopper; 2. Feed regulation handwheel; 3. Disc nut; 4. Stationary iron disc; 5. Stationary abrasive surface; 6. Rotating abrasive surface; 7. Rotating iron disc; 8. Husked rice and hull outlet; 9. Disc housing; 10. Frame; 11. Base; 12. Drive shaft; 13. Upper bearing; 14. Drive belt; 15. Drive pulley; 16. Lower bearing; 17. Disc clearance adjustment handwheel; 18. Shaft supporting arm.

103). This machine consists of two horizontal discs separated by about the length of a rice grain. The opposed surfaces are coated with an abrasive emery-cement mixture. When in operation, the upper stone remains stationary while the lower revolves rapidly with a stream of rice being fed through an opening in the center of the upper stone. Centrifugal force throws the rice outwardly between the stones and as it passes to the periphery of the discs, the grains are upended, and the hulls are cracked, permitting them to break away from the kernels. The hulls

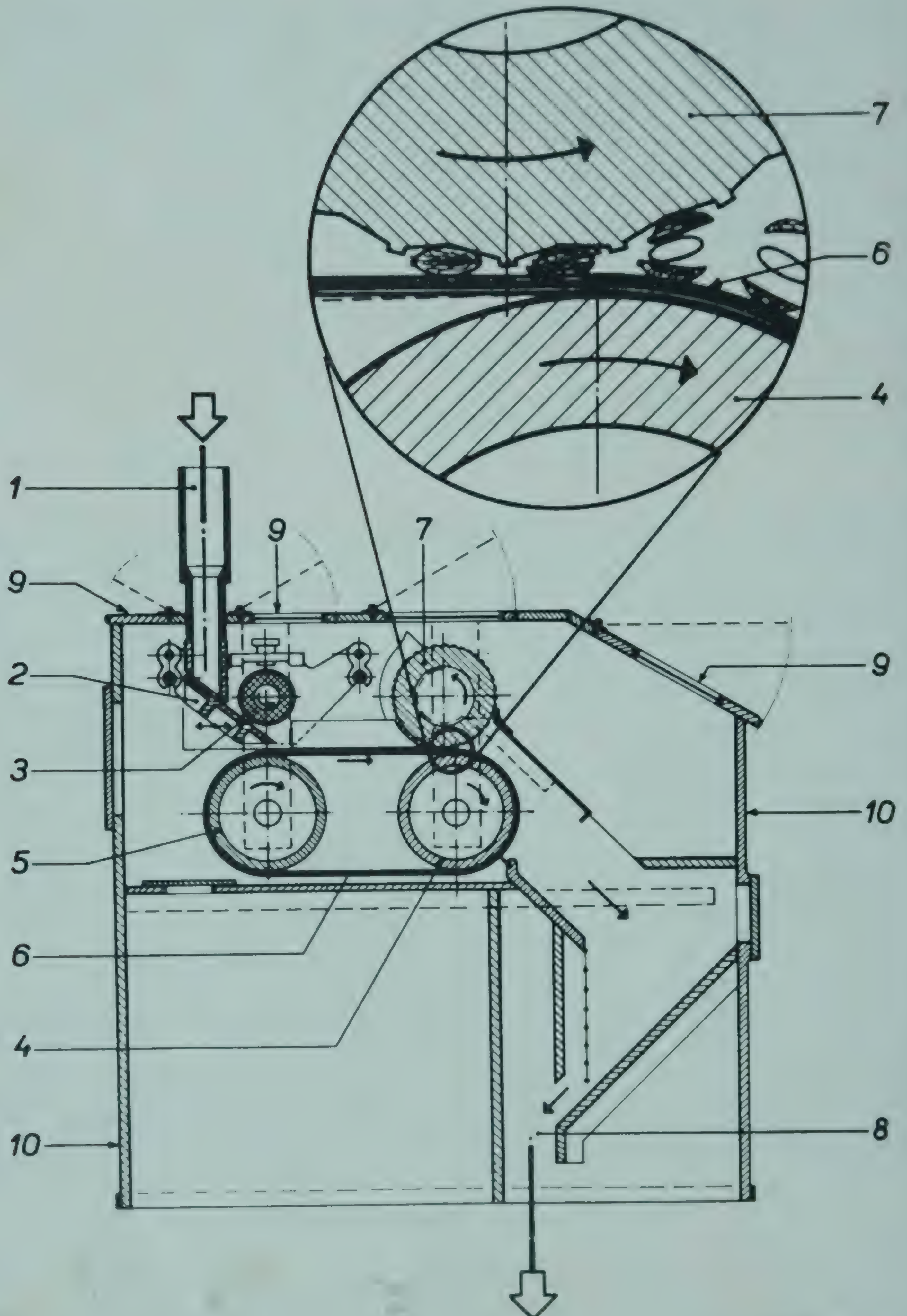
are comparatively light and are readily removed from the shelled grains when the mixture is aspirated through a cyclone separator. The brown rice produced in the shelling process contains some small unshelled rice grains which must be separated. This operation is performed in an ingenious device known as a paddy separator, which consists of flat cars divided into three tiers of irregular compartments (Fig. 104). The cars are tilted in such a way that when they are rapidly shuttled, the lighter, bulkier, rough rice (commonly called paddy) is concentrated at the raised side, while the heavier brown rice migrates to the lower opposite side. The process is continuous, and streams of brown and rough rice are removed simultaneously. The unshelled paddy is then fed into another pair of shelling stones set closer together than the first set, and the above process of shelling, aspiration, and separation is repeated.



Courtesy of Farmers Rice Growers Cooperative

FIG. 104. PADDY SEPARATORS SHOWING ARRANGEMENT OF COMPARTMENTS

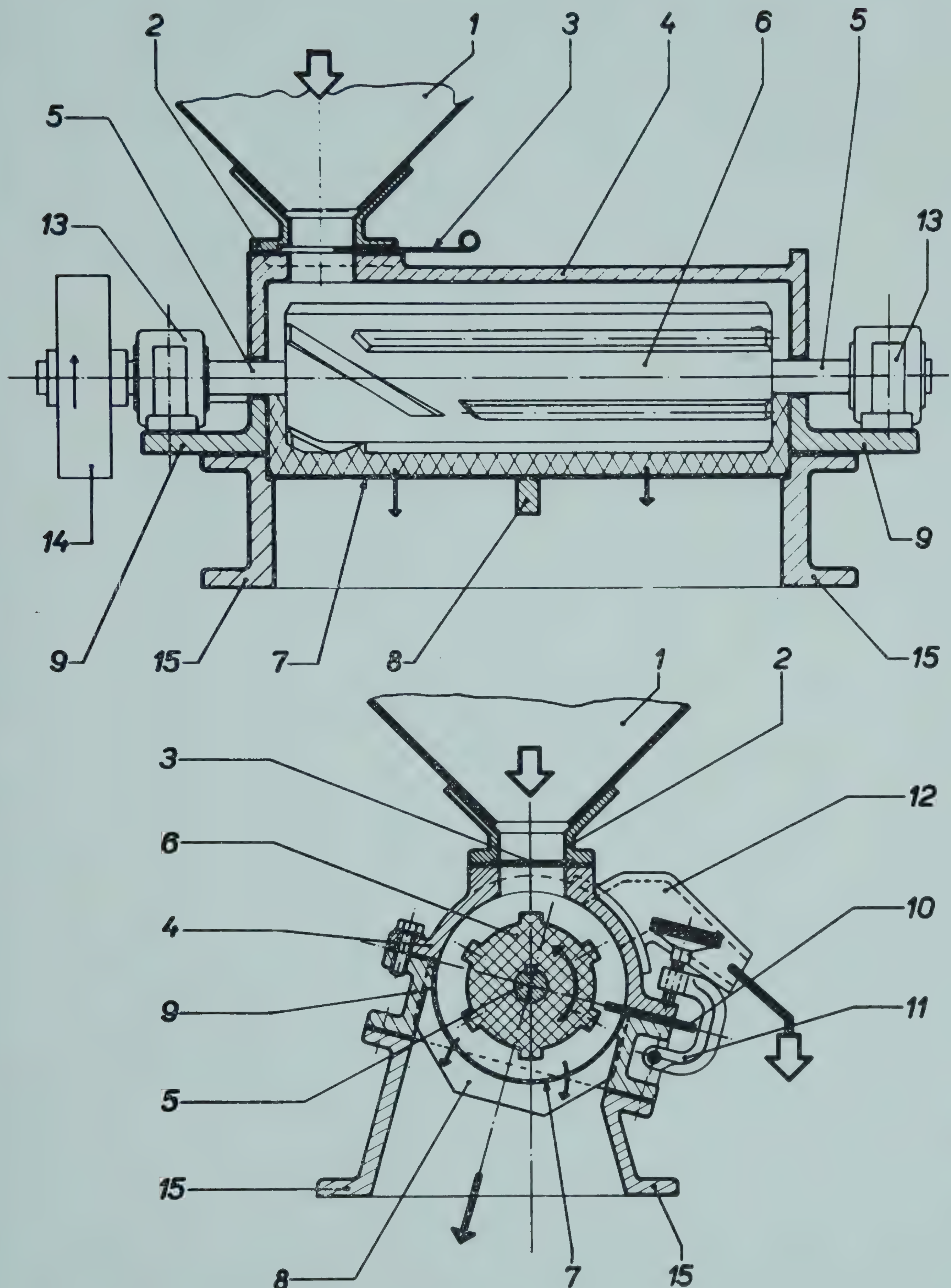
Rough rice may also be shelled between rubber rolls or with a rubber belt operating against a ribbed steel roll (Fig. 105). This device is quite effective but the abrasive hulls wear down the rubber, which must be replaced after a time. It is less bruising on the bran layers of the brown rice, however, than shelling stones, and brown rice produced in rubber shelling devices is more resistant to fatty acid development in the oil fraction (Houston *et al.* 1952).



Courtesy of FAO

Fig. 105. Rubber Belt Huller

1. Feed hopper; 2. Feed plate; 3. Feed roller; 4. Stationary roll; 5. Belt tension roll; 6. Rubber hulling belt; 7. Ribbed steel hulling cylinder; 8. Discharge for hulls and hulled rice; 9. Inspection doors; 10. Housing and frame.



Courtesy of FAO

FIG. 106. RICE MILLING MACHINE

1. Feed hopper; 2. Hopper seat; 3. Feed regulation gate; 4. Cover; 5. Shaft; 6. Ribbed rotor; 7. Slotted screen; 8. Screen holder; 9. Upper frame; 10. Blade; 11. Cover clamp; 12. Discharge; 13. Bearings; 14. Drive pulley; 15; lower frame.

Whether produced by stone or rubber shellers, the brown rice is now ready for milling.

Brown rice is first milled to remove the coarse outer layers of bran and germ. The most common device used in United States' rice mills for this operation is erroneously called a huller. It is more properly referred to as a milling machine. Unlike the milling of wheat flour in which fine particle size is desired in the product, rice milling must be conducted to break as few kernels as possible because whole grains or head rice are of more commercial value than broken grains. The difference in price may be from 1.5 to 6 cents a pound.

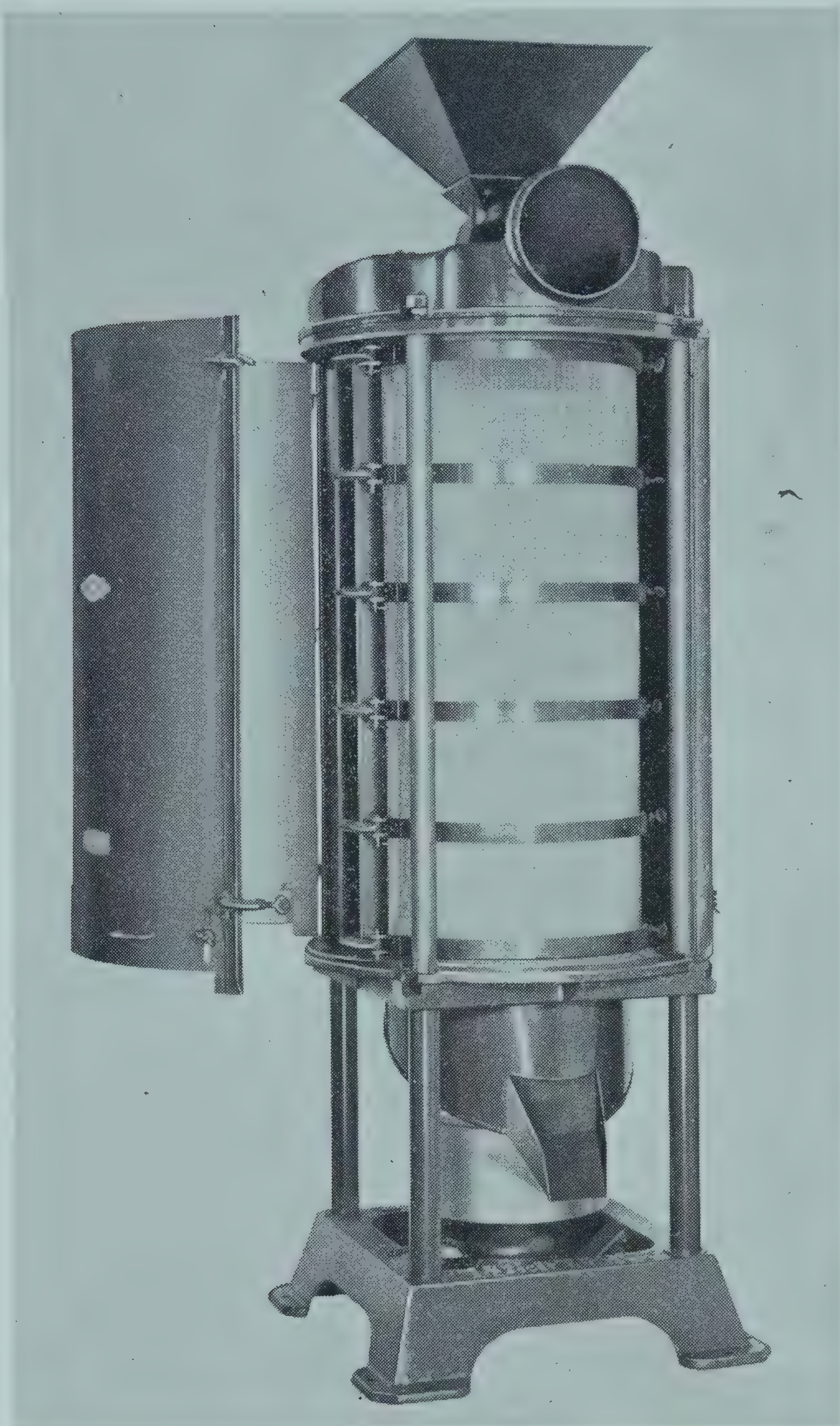
The conventional milling machine is illustrated in Fig. 106. The outer part consists of a hollow horizontal cylinder, the lower half of which is slotted. The upper half contains an adjustable longitudinal blade. Inside the outer shell is a ribbed steel rotor. The blade is adjusted so as to force the grains of rice against the rotating ribs. Brown rice is fed into the milling machine at the top until the annular space is filled, and the grains are rubbed by the ribbed rotor and by each other to remove bran and germ which are forced through the slots by internal pressure. There is always a certain amount of breakage in rice milling, and the finer bits of broken endosperm pass out of the mill along with the bran and germ. The milled rice is removed after it has progressed through the machine by the spiral action of the ribs.

Milling may be accomplished in one or two "breaks"; that is, by a single passage through a mill or by consecutive passages through two mills, depending on plant practice. In some plants, as many as four breaks have been used.

After the rice is milled, it consists of almost white whole kernels mixed with broken kernels of different sizes. It is now ready for the brush—a device for removing the white inner bran layers plus the proteinaceous aleurone layer. The brush is essentially a large vertical stationary cylindrical screen inside of which rotates a drum to which is attached overlapping leather flaps (Fig. 107).

The rice enters the annular space of this machine at the top and, as it progresses toward the bottom, is rubbed against the screen by the leather flaps. The white floury mixture of fine bran and aleurone layer removed by abrasive action is forced through the screen and is collected and sacked.

At this point, the rice is fully milled. Some trade outlets, however, require that the rice have a high luster. This operation is performed in trumbols (Fig. 108) which are large, horizontal, rotating drums fitted with lengthwise baffles. The milled rice is charged into the trumbols and treated with talc and glucose solution while the trumbols are rotated.



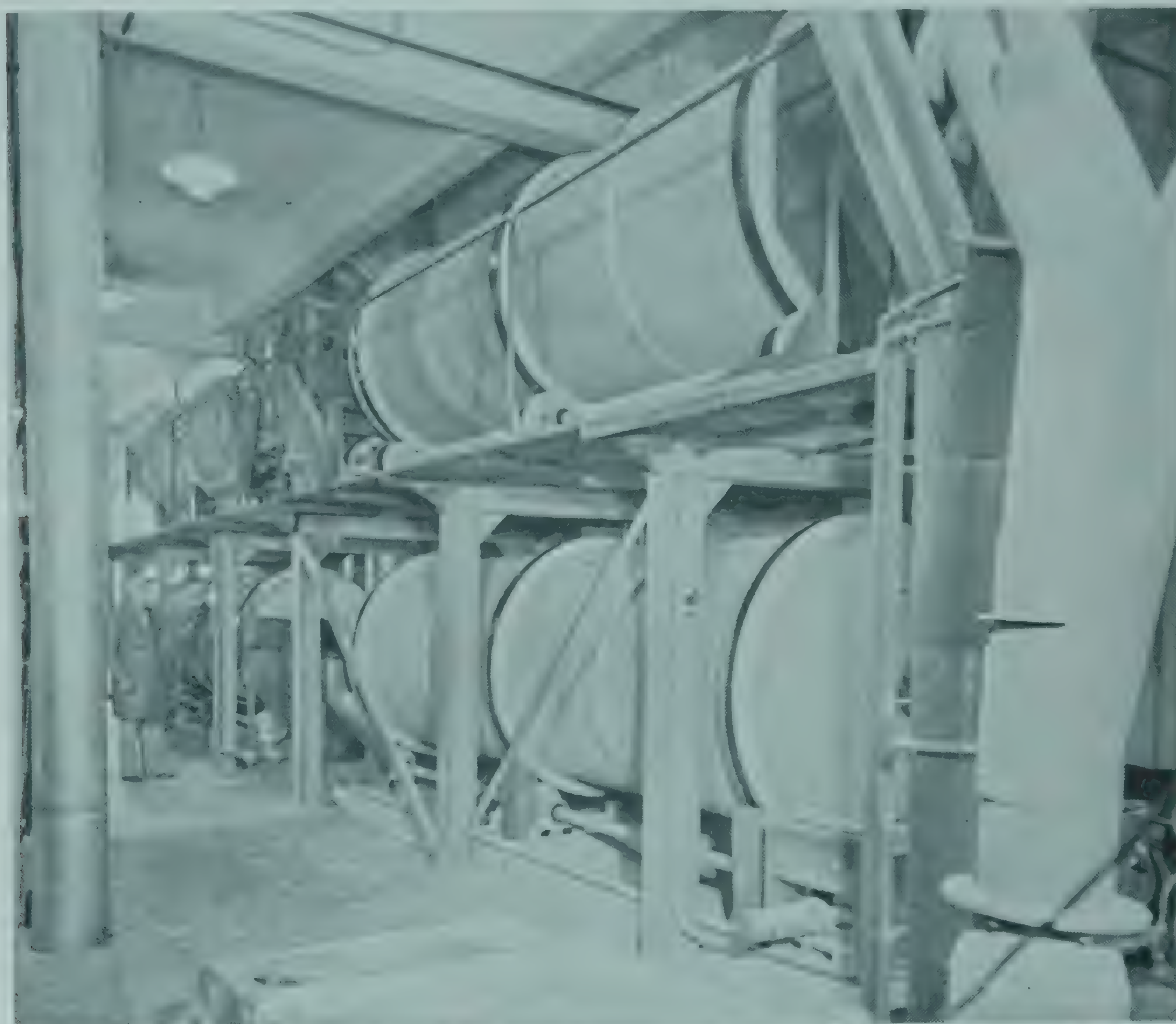
Courtesy of Engelberg, Inc.

FIG. 107. RICE BRUSH

After the coating is evenly distributed on the kernels and dried with warm air, the rice emerges from the equipment with a smooth, glistening luster and is known as coated rice.

The mixture of whole and broken kernels obtained in the milling process is usually separated to meet certain grade requirements for milled rice. This operation is performed in two types of equipment. One is a rotating horizontal cylinder, the inside surface of which contains closely spaced depressions so shaped and of such a depth that when the cylin-

ders are rotated, broken grains lodge in the depressions, are carried upward as the cylinder revolves, and fall out when it has rotated through a sufficient arc. They are collected in a discharge device and are carried out of the cylinder. Unbroken grains are too long to lodge in the depressions, move along the lowest part of the cylinder, and discharge at the end opposite the point of loading.

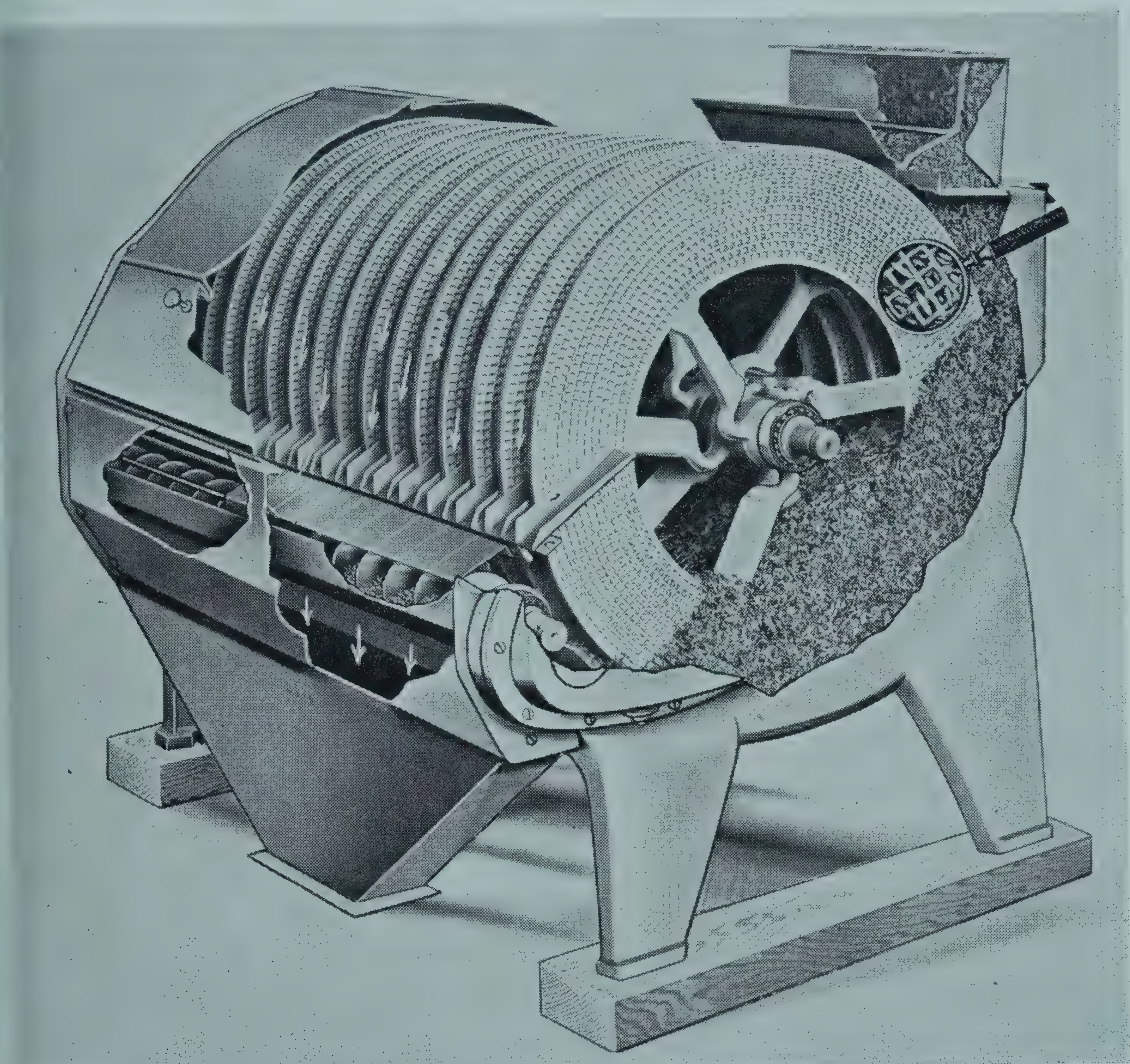


Courtesy of Farmers Rice Growers Cooperative

Fig. 108. Trumbols for Coating Rice

In recent years, the indented cylinder has been replaced in many plants by the disc separator (Fig. 109). This is also a horizontal cylinder in which revolves a series of parallel indented discs. The indentations are designed with one deep side and one shallow side. As the discs rotate through a moving bed of rice in the lower part of the cylinder, the broken grains lodge against the deep side of the depressions, are carried upwards, and fall out at or slightly beyond the zenith of rotation. Like the indented shell type of separator, the operation of this device is continuous. By proper choice of conditions, such as rate of feed and speed of rotation of the discs, an almost complete separation of broken grains from the head rice can be achieved. These machines are provided with sets of discs

having depressions of different size for use on different kinds of rice. Discs designed for the short-grain Caloro rice, for example, would not be suitable for long-grain types such as Bluebonnet.



Courtesy of Hart-Carter Co.

FIG. 109. DISC SEPARATOR FOR SEPARATING WHOLE AND BROKEN KERNELS OF RICE

The broken grains of rice removed from the head rice by either the indented shell or disc separator, are further classified by screens, vibrating tables or disc separators with smaller indentations into "second heads," "screenings," and "brewers' rice," which are in the order of increasing fineness of particle size. In some localities, brewers rice and screenings are combined and sold as brewers rice. These broken grades do not command so high a price as head rice, but they find use in the brewing industry and in making rice flour, pet food formulations, etc. Second heads are sometimes recombined in certain proportions with head rice to meet special trade specifications.

In a pilot plant study of rice milling operations, Autrey *et al.* (1955) found that most of the breakage of long- and medium-grain rice during passage through the various units of equipment occurred in the milling machine. Average of 29 runs showed that 5.0 per cent of the kernels were broken in the sheller, and 9.6 per cent in the milling machine. The brush accounted for 3.1 per cent of the breakage (average of 17 runs). The variations among samples in all three units, however, were extremely wide. Breakage in other equipment of the mill such as the cleaner, paddy machine, and broken rice separator, was negligible. In this reference, the authors also reported that when the air of a rice mill was properly humidified, breakage was greatly reduced. A relative humidity of about 70 per cent, which was in approximate equilibrium with the moisture content of the rice being processed, gave maximum head yields. Most important was humidification in equipment where the rice came in contact with large volumes of air, particularly in the aspirators and elevators.

MARKET QUALITY OF RICE

Six grades of rough, brown, and milled rice (above "sample" grade which is only suitable for feed), regardless of variety or type, are recognized, for which rigid standards have been established by the U. S. Agricultural Marketing Service. Rice of all grades must have 14 per cent or less moisture content; otherwise it is classed as damp rice. Specifications for the different grades include maximum limits of heat-damaged kernels, chalky rice, rice of contrasting classes (i.e., long-grain and short-grain), red rice, and weed seeds, and the color of fully milled samples. Milled and brown rice grades include maximum limits for broken rice. Rough rice is sold on the basis of the amount of milled rice and the amount of head rice (whole kernels) obtained when the rice is milled by a standard milling test. There are also standard specifications for broken grades of rice.

To illustrate the requirements of a grade, U. S. No. 1 milled rice must contain not more than one heat-damaged kernel or objectionable seed in 500 gm., nor more than 0.5 per cent of red rice, 1 per cent of chalky kernels, 4 per cent of broken rice and 1 per cent of rice of contrasting classes, and must be white or creamy in color.

The difference in returns that can be expected from rice at different market quality levels can best be illustrated by comparison of support prices. Thus, in 1956, No. 1 California Pearl or Calrose rices which yielded on milling 48 lbs. of head rice and 22 lbs. of broken kernels was supported at $4.22 per cwt., No. 2 at $4.12, No. 3 at $3.97, No. 4 at $3.82, and No. 5 at $3.62.

UTILIZATION OF HULLS, BRAN, AND POLISH

Rice hulls whose composition is given in Table 83, are more of a liability than an asset to millers, who often pay for their disposal. Various practical applications have been proposed and part of the hulls from the United States rice crop do yield some monetary returns either directly or indirectly. They are used for stock litter, soft grit blasting of metals, soil conditioning, polishing of semi-precious gems, making activated chars, and as boiler fuel in rice mills. In times past they have been used for production of furfural and in formulations of light-weight concrete blocks. With a k value of about 0.25 they are between asbestos and mineral wool in thermal insulating properties. They have also been found useful as a seed diluent for drill planting and, in this respect, are said to be superior to sand or sawdust in maintaining uniform distribution, particularly of mixed seeds. The Soil Conservation Service, which discovered this interesting application of rice hulls, has continued to use them in the seeding of forage grasses. Although rice hulls are low in food calories, limited amounts of them can be used in feeds without injury to animals.

TABLE 83

COMPOSITION OF RICE HULLS AND RICE HULL ASH[1]

	Per cent
Rice Hulls	
Moisture	2.4–11.0
Ash	15.7–21.3
Protein	2.4– 3.6
Ether extract	0.9– 1.2
Crude fiber	39.0–45.7
Nitrogen-free extract	24.7–29.4
Rice Hull Ash	
Silica	94.0–94.5
CaO	0.3– 2.3
MgO	0.2
K_2O	1.1– 3.2
Na_2O	0.8
Fe_2O_3	Trace to 0.1
SO_3	1.1
P_2O_5	0.5
Al and Mn oxides	Trace

[1] Range of reported values.

At present, however, most of the rice hulls from U. S. mills amounting to about 400,000 tons a year are burned as a disposal measure. The resulting ash (about 20 per cent of the hulls, and mostly silica) finds some use in sweeping compounds for garage floors, in mechanics' soap, and in ceramic ware.

The problem of finding a large-scale use for rice hulls remains. The importance of solving it has been repeatedly emphasized by the rice

milling industry, and rich rewards are in store for the person or team of workers who will come up with the answer.

Rice bran, one of the most nutritious parts of the rice grain (Table 81) is used almost exclusively as a feedstuff. It contains 13 to 15 per cent of oil which is quite unstable when left in the bran, since it then develops free fatty acids at a rapid rate. Three plants in the United States currently extract rice oil with petroleum solvents, and obtain a high grade, relatively stable product that is useful for general culinary purposes, deep fat frying, and in food formulations. The bran after extraction is more stable than before, but is quite dusty and is often pelleted with molasses. Some rice bran is used in the manufacture of vitamin B concentrates.

Rice Polish

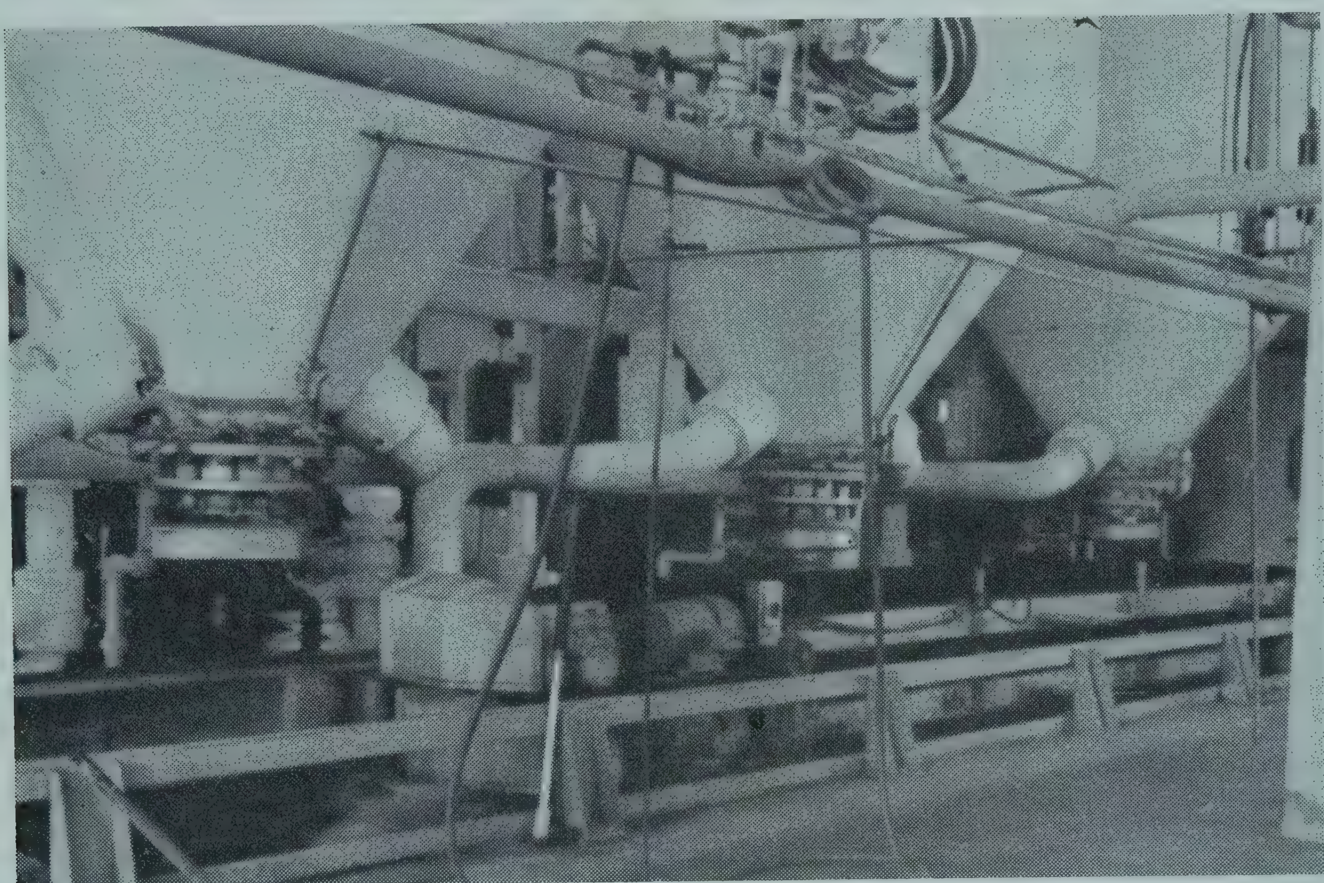
Considerable quantities of rice polish are sold for baby food formulations, and in health stores, but much of the annual production goes into feedstuffs. Like rice bran, rice polish is rich in nutrients.

RICE PROCESSING

About 15 per cent of the national rice crop is processed into prepared foods of various kinds—parboiled, quick-cooking, enriched, and canned rice, canned soups, canned rice and vegetable mixtures, dry soup mixes, breakfast cereals, baby foods, and frozen dishes. When ground into flour, rice is sometimes used as a thickening agent in canned goods because of its smooth texture, and bland flavor. Rice flour is also used in commercial bakeries for dusting loaves of bread before they go into the oven to give a golden brown color to the crust. Because rice, unlike wheat, is lacking in gluten, it cannot be used by itself for making bread and, even when admixed with wheat flour, reduces loaf volume in proportion to the amount of rice flour present. Broken grades of rice are frequently used as a source of carbohydrates in brewing. Because natural antioxidants present in rice are usually destroyed in processing rice, protective agents are often added to rice products to inhibit rancidification. Butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) have been found particularly effective for stabilizing rice products (Stuckey 1955). Even well milled rice contains a small percentage of fat (Table 81) which is not removed by processing treatments and may cause trouble when rice products are stored. The natural nutritional deficiencies of milled rice may be still further increased by certain types of processing but may be compensated for by adding vitamins, iron salts, and protein supplements containing essential amino acids to the products.

Parboiled Rice

The parboiling of rice has been practiced for hundreds of years in a primitive way in foreign countries, particularly Burma, India, and Pakistan. The method in its original form was to boil rough rice for an hour or so in open kettles; then it was spread on the ground to dry and hand-pounded for use when needed. Manufacturing processes for parboiling rice have been introduced into the United States, Italy, and British Guiana since 1940. More recently, mechanized methods similar to those of the United States have been adopted in Burma.



Courtesy of Converted Rice, Inc.

Fig. 110. Pressure Steeping Tanks Used in Parboiling Rice

Four plants presently manufacture parboiled rice in the United States. The processes have been described in technical articles (Anon. 1948, Court 1946, Havighorst 1947, Jones and Taylor 1935, Jones *et al.* 1946, and O'Donnell 1947), and are covered by numerous patents (Baumgartner 1917, Huzenlaub 1942, and 1949, Huzenlaub and Rogers 1941, 1944, 1951, 1951A and 1952, Landon *et al.* 1951, and Yonan-Malek 1943, and 1943A). They are similar in that all involve soaking rough rice, steaming, drying, and finally milling it. The soaking step is carried out in warm water. In one variation, rough rice is elevated from storage bins to an automatic hopper scale which weighs and dumps the rice into an accumulating hopper. When sufficient rice is assembled for a batch, it is dumped into a steeping tank (Figure 110). This vessel is connected to a vacuum system, a water system, and a compressed air system. When the batch of

rice is dropped, the tank is evacuated to remove air from the grain. Then sufficient water heated to about 200° F. is introduced to cover the rice. The tank is pressurized to about 100 lbs. per sq. in. and the rice is steeped about 190 minutes. The temperature and time may be varied somewhat depending on the specific characteristics of the rice used, its moisture content, time in storage, etc. During the steeping step, water soluble Vitamin B components and minerals are infused into the endosperm from the bran, germ, and hull. At the end of this operation, the water is drained off, and the rice is discharged into a jacketed rotating vacuum drier equipped with steam tubes (Figure 111).

Courtesy of Converted Rice, Inc.

FIG. 111. ROTARY STEAMER

The drier is evacuated and heated with steam to remove excess moisture from the rice. Dry steam is then injected to gelatinize the starch in the grains, after which the vessel is vented and evacuated until the moisture is low enough in the rice to permit milling. The dried rice is conveyed to bins where it is cooled by drawing air through it, and tempered to equalize the moisture content of the batch. Finally the rice is milled to remove hull, bran, and germ.

In another process, cleaned rice is steeped in two parts of water at 130° to 150° F. in open steel tanks for 9 to 12 hours until it has absorbed 30 to 35 per cent moisture on the wet basis. The soaked rice is transferred continuously to a vertical pressure vessel equipped with rotary valves on the inlet and discharge openings and steamed at 230° to 245° F. for 8 to 20 minutes, depending on the degree of parboiling and the cooking quality

and color desired in the end product. Shorter cooking times result in lighter colored rice. Little additional water is absorbed in the steaming process, and the rice is discharged with a moisture content of about 35 per cent. It is dried in a steam tube drier and a series of hot air driers to 11 to 13 per cent moisture, then milled in conventional equipment. Yields are from 66 to 71 lbs. of total milled rice and 58 to 67 lbs. of whole grains per 100 lbs of starting rough rice. The product is said to contain 2.0 micrograms of thiamin, 0.40 micrograms of riboflavin, and 44.0 micrograms of niacin per gram of dry material. Its storage life is from 2 to 3 years. Milling by-products are disposed of in the regular commercial channels for these materials. The waste water from the steeping is not utilized.

A third process is similar to the second in general principle, but both the soaking and steaming steps are performed in rotating cylinders (Court 1946, Havighorst 1947).

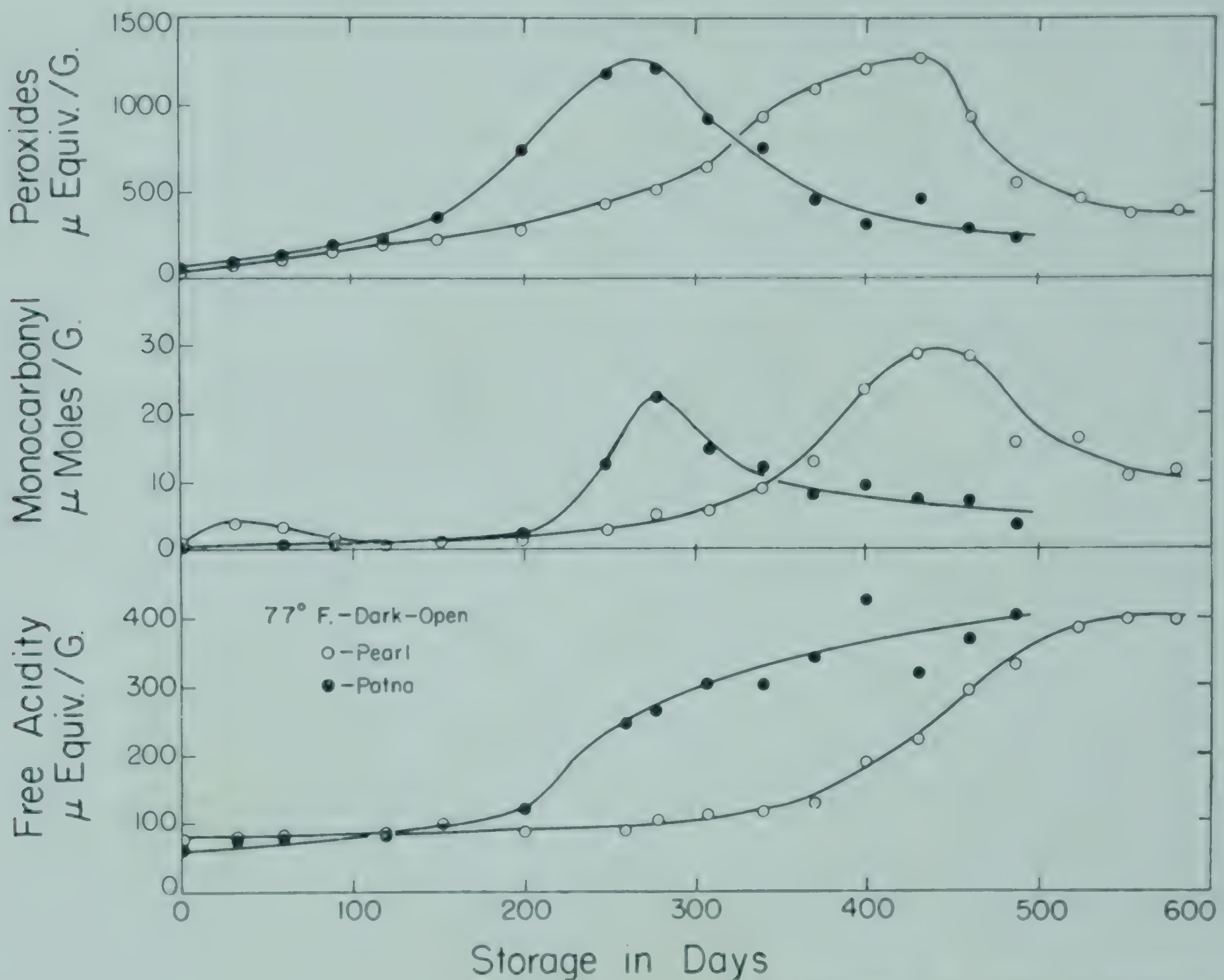
Parboiled rice has a somewhat rubbery texture and, for that reason, resists breakage when it is milled. The better head yields obtained in the milling of parboiled rice than in the milling of raw rice defrays to a considerable degree the cost of parboiling so that parboiled rice sells for little more than white rice.

Although parboiled rice is not quick cooking, it has certain advantages over raw rice—it is more nutritious, it is more resistant to insect infestations, and it can be used in canned formulations such as soups and other semi-liquids without disintegration. It can be cooked with less danger of becoming mushy than white rice. Parboiled rice is not so white as raw milled rice and has a slightly different flavor, but it is widely accepted and is often preferred to white rice. In some rice-eating areas of the world, however, attempts to introduce it have not been successful. Its color, which is usually a light tan, may be an adverse factor in instances where extreme whiteness of rice is a criterion of quality.

When parboiled rice is stored, rancidity occurs following an induction period. This effect is accompanied by a rise in fat acidity and in monocarbonyl and peroxide values. Both monocarbonyls and peroxide rise to a maximum, then decrease, and simultaneously the rancid odors begin to subside and ultimately disappear. Fatty acids continue to rise during storage, but the rate of increase diminishes as storage advances.

The behavior of the fat fraction in Pearl and Patna parboiled rice, with respect to development of oxidation products and free fatty acids, has been experimentally studied under a variety of conditions including dark and light storage, closed and open containers, and at several temperatures (Houston *et al.* 1954). In open containers, dark storage of both rices showed maximum carbonyl values at 77°, 100°, and 180°F. in

about a year, a month, and a week, respectively. Fig. 112 illustrates changes in monocarbonyl, peroxide and free fatty acid values at 77°F. In closed storage at 77° and 100°F., peroxide and monocarbonyl changes were similar to those for open storage, but induction periods were longer. At 140°F., no significant rise of either function was observed. The accelerating effect of light on rancidification of fat-containing foods was confirmed for parboiled rice during storage at 77°F.



Courtesy of Food Technology

FIG. 112. CHANGES IN OIL DURING OPEN STORAGE IN THE DARK AT 77°F.

In a separate study (Houston *et al.* 1956), the effect of storage on color changes in parboiled rice at different temperatures was measured. For both Pearl and Patna rices, color changes were negligible for about a year at 77°F. in either open or sealed containers. At 100° and 140°F., color changes were observed after 3 or 4 months due to nonenzymatic browning, accompanied by losses of reducing sugars. Amino nitrogen and free amino acids were also reduced in amount (Hunter *et al.* 1956). Sulfur dioxide added during processing inhibited browning of parboiled rice but did not delay rancidification.

As parboiled rice is frequently sold in small permeable packages, and moves from factory to consumer rather rapidly, little difficulty is experienced with rancidity on retail store shelves. But when stored in bulk,

it occasionally "goes off" in large quantities, and manufacturers of this product now stabilize it with high-potency antioxidants, which have proved quite effective. Close milling of the rice to reduce its fat content is also practiced, but always a few tenths of a per cent of fat remains and this is enough to cause trouble unless it is stabilized in some way.

Parboiled rice expands to a light porous product when heated in hot air or hot oil (Roberts 1952, Roberts *et al.* 1951). Roberts *et al.* (1954) made an intensive study of the influence of parboiling conditions on various properties of rice, including its color, the solubility of the amylose fraction, and the extent of expansion upon heating under controlled conditions. The steaming step in the parboiling of rice had a particularly great influence on these properties, the expansibility of the grains, depth of color and starch solubility in the final product increasing decidedly with the severity of the treatment.

Expanded parboiled rice is usable as a dry breakfast cereal but for that purpose its comparatively bland flavor should be enhanced with other ingredients such as honey, malt syrup, salt, etc. Precooked brown rice, when expanded with toasting, and finally ground to farina size, has been patented as an instant-cooking breakfast cereal (Kester and Ferrel 1957).

Quick-Cooking Rice

The modern trend in processed foods is toward convenience items. The day of long, drawn-out preparation of food is fast disappearing. Housewives are relying more and more on canned, packaged, or frozen foods to serve their families. Food processors and research agencies have been eminently successful in developing tasty products in these categories. Rice, because of its bland flavor, lends itself readily to various forms of preparations and formulations. Parboiled rice, described in preceding pages of this chapter, is a case in point. This form of rice, however, although fully precooked, is not a quick-cooking rice for the reason that the grains are still quite dense and therefore do not take up water readily. Other dry forms of precooked rice are now available with a more open texture and may be prepared for serving in from 2 to 15 minutes. Some are made by precooking in water and drying under special and closely controlled conditions; others are made with dry heat. Following are some of the methods used for preparing forms of quick-cooking rice.

In one commercial method, the cooking time of both brown and white rice is shortened by heating the dry grains in a current of air at elevated temperatures. The rice kernels are so modified by fissuring of the surface layers, by dextrinization, and, in the case of brown rice, loosening of the bran layers, that the cooking time of the product in the home is reduced to about a half or one-third that of the raw rice. This represents an ex-

tremely important saving of cooking time, especially for brown rice, which, when not so treated, requires 35 to 45 minutes of cooking to make it soft enough to eat. Heat-processed brown rice is improved nutritionally by coating it with thiamin, riboflavin, and iron phosphate, and is stabilized against rancidification with antioxidant. These elements are applied at one time in a water-vegetable oil emulsion. Unlike fortified or enriched raw rice, enriched heat-processed rice is not coated with a protective film. But it should not be rinsed before being cooked for serving.

Other forms of quick-cooking rice are made by precooking white rice and either rapidly drying the cooked product in a current of hot air or slow drying followed by expansion of the dried grains with heat. A large number of patents (Alderman *et al.* 1953, Campbell and Hollis 1954 and 1954A, Flynn and Hollis 1955, Hollis *et al.* 1958, Knoch 1955, Mickus and Brewer 1957, Muller 1952, Ozai-Durrani 1948, 1950, 1955, 1956, 1956A, 1956B, and 1958, Roberts 1952A and 1955, and Shuman and Staley 1954) have been taken out that cover different variations of the wet process for making quick-cooking rice.

One widely sold form of quick-cooking rice can be prepared for serving in about five minutes. It is enriched with thiamin, riboflavin, niacin, and iron. Actual details of the commercial method for manufacturing this product are not available, but they probably follow the general methods outlined above and are continually being modified to obtain improvement in texture and nutritional value of the product and to reduce processing losses.

In the original form of this process, the rice was gelatinized in one step by completely cooking it in water (Anon. 1947 and 1949). This procedure resulted in extensive losses due to overcooking of the surface layers of the grains which dispersed into the cooking water. In one modification (Flynn and Hollis 1955), the soaked rice is steamed under pressure to partially gelatinize the grains, which are then slightly compressed. They are retreated with hot water to enlarge the grains and complete the gelatinization process. After these treatments the rice is dried under conditions which produce a slight puffing action.

Quick-cooking rice may also be made by first heating the raw grains in hot air or by infrared radiation (Campbell and Hollis 1954 and 1954A; Shuman and Staley 1954) then gelatinizing them with moisture and heat, followed by quick drying to set the grains in their enlarged porous condition.

In another patented process (Carman and Allison 1953, 1953A) cooked rice is expanded by heating it under pressure and suddenly relaxing the pressure into a vacuum chamber.

Still another process for making quick-cooking rice is a novel variation of prior methods. It consists of soaking and cooking rice, then freezing, thawing, and dehydrating it (Keneaster and Newlin 1957). The product is said to recook in about five minutes. Details of a similar process have been discussed by Roseman (1958).

The property possessed by dried gelatinized rice, of expanding under heat treatment (Roberts 1951 and 1952) is most advantageous in the preparation of quick-cooking rice products. The degree of expansion in hot air may be as high as four-fold when the proper conditions are maintained. The grains retain their normal shape after expansion but are crisp and porous. Addition of boiling water causes them to shrink to about the size of boiled white rice grains.

Canned Rice

Canned cooked rice may also be considered a form of quick-cooking or quickly prepared rice. Formerly it was made almost exclusively from parboiled rice because this form of rice, unlike cooked white rice, does not disintegrate when the cans are sterilized. Roberts (1954) and Roberts *et al.* (1953) of the Western Regional Research Laboratory surmounted the difficulty of canning white rice by limiting the moisture content of the product to about 55 per cent. Briefly, this process consists of: (1) soaking the rice to its equilibrium moisture content (about 30 to 35 per cent water); (2) cooking it 4 to 5 minutes in excess water; (3) draining and packing the rice into cans; and (4) vacuum sealing and retorting. This rice may be prepared for serving by adding a small amount of additional water and heating for about two minutes until the added water is absorbed.

The critical points of this process are: (1) limitation of the moisture content as described, (2) adjustment of the pH in the product before canning to about 5.5 to 6.0, (3) packing in C-enamel cans or glass jars with C-enameled lids, and (4) sealing under at least 26 inches of vacuum.

It is important that the moisture content of white rice cooked for canning be in the range of about 50 to 55 per cent. Less moisture than 50 per cent makes the rice too dry and hard to absorb the additional water readily and more moisture than 55 per cent causes the rice to become pasty during canning and retorting.

Frozen Cooked Rice

Both white and brown rice after cooking can be frozen and stored for several months to a year without deterioration (Boggs *et al.* 1951 and 1952). In fact, white rice actually seems to improve in different respects with frozen storage according to the verdict of a taste panel. At the

Western Regional Research Laboratory where frozen rice was developed and studied, rice was first soaked, then cooked to a slightly underdone state, quick frozen in a blast freezer, and finally stored at sub-freezing temperatures (−10°, 0°, and 10°F. for white rice, 0° for brown rice). At periodic intervals, the rice was thawed and prepared for serving by heating ten minutes in a steamer, then graded by the sensory panel on the basis of texture, cohesiveness of grain and flavor. Color was graded on the white rice samples only. Although no commercial development of these frozen rice products seems to have been made, they should have a widespread acceptance as convenience items. Because no satisfactory method has been found for preventing the rice grains from cohering in a cake during freezing, it has been suggested that the rice be frozen in thin sheets to avoid the need for penetrating a thick solid mass of frozen rice with steam. Part of the experimental packs of rice have been in frozen storage for six years and have retained to a high degree their original qualities of flavor and texture.

USES OF WAXY RICE FLOUR IN FOOD PRODUCTS

In tests of numerous thickening agents for white sauces, gravies, and puddings, waxy rice flour had superior properties in preventing liquid separation (syneresis) when these products were frozen, stored, and subsequently thawed (Hanson *et al.* 1951, 1953 and 1957). Regardless of the thickening agent used, storage temperature proved to be an important factor. At 0°F., a white sauce thickened with waxy rice flour showed little or no separation when thawed at the end of a year; puddings made with this flour and egg yolk had a storage limit of about four months, and when made with the flour and whole egg, about two months. When these products were stored at 10°F., however, the storage life was only approximately one-fifth that at 0°F.

The fact that waxy rice contributes this phenomenal property to frozen foods of the kind described, is doubtless because its starch is almost pure amylopectin. By way of partial explanation of its behavior, the following observation of Kerr (1950) is cited:

> "Solutions of starch which have aged at room or lower temperature undergo the phenomenon of retrogradation. A part of the starch aggregates progressively, and finally forms an insoluble microcrystalline precipitate. . . . The retrogradation process may be hastened by freezing aqueous solution; in this way, ordinarily stable solutions may be forced to retrograde. Although some amylopectin preparations have a tendency to retrograde from solution, the property is greatly exaggerated in pure amylose solutions."

The inference drawn by Hanson *et al.* (1951) is that the common starches containing unbranched molecules would be expected to retro-

grade and eliminate water more rapidly than amylopectin starches under comparable conditions.

Bates *et al.* (1943) reported that amylopectins from different starches do not behave alike in an iodine titration. In their tests, the more highly branched the amylopectin, the less was its affinity for iodine. Of the polysaccharides investigated, glycogen had the least affinity for iodine, followed by waxy rice, waxy corn, waxy barley starch, and potato and corn amylopectin. Meyer and Fuld (1941) found that the degree of branching of waxy rice starch is between that of ordinary amylopectins and of glycogen and that the waxy rice starch molecules are of low and intermediate molecular weights. In the investigations at the Western Regional Research Laboratory, liquid separation in sauces containing waxy corn and waxy sorghum starches occurred in shorter storage times than in sauces containing waxy rice starch or flour. This was further evidence that the waxy cereal starches differs in molecular size and degree of branching.

In a separate investigation, it was found that waxy rice flour had desirable properties when used as a thickening agent in canned products (Davis *et al.* 1955). Pastes prepared from it showed essentially no increase in gelation or separation of liquid during storage. Other waxy cereals possess this property also, but waxy rice has the advantage of imparting a "short" or non-stringy character to the paste. Use of waxy rice flour with wheat flour for pastes is indicated when a certain amount of initial gelation, but no increase in gelation during storage, is required.

ENRICHMENT

The use of highly polished rice has been a public health problem in many places where rice is a main article of diet. Beri-beri or severe B-complex deficiencies are often endemic in these areas. A test in the Bataan province of the Philippines from 1947 to 1950 (Salcedo *et al.* 1950) demonstrated conclusively the value of rice enriched with thiamin, niacin, and iron for reducing incidence of and mortality from beri-beri. The results of the test were so dramatic that the Philippine government maintained enrichment of rice in Bataan and has gradually extended it to other provinces. In 1951 the Puerto Rican government enacted legislation requiring that all rice sold on the island be enriched. And in our own country, South Carolina, which has a high per capita consumption of white rice, passed a law requiring that only enriched rice be sold within the State after July 1, 1956. Enriched rice has also been made available in Cuba, Venezuela, Columbia, Dominican Republic, Taiwan, Singapore, Australia, Hawaii and Thailand.

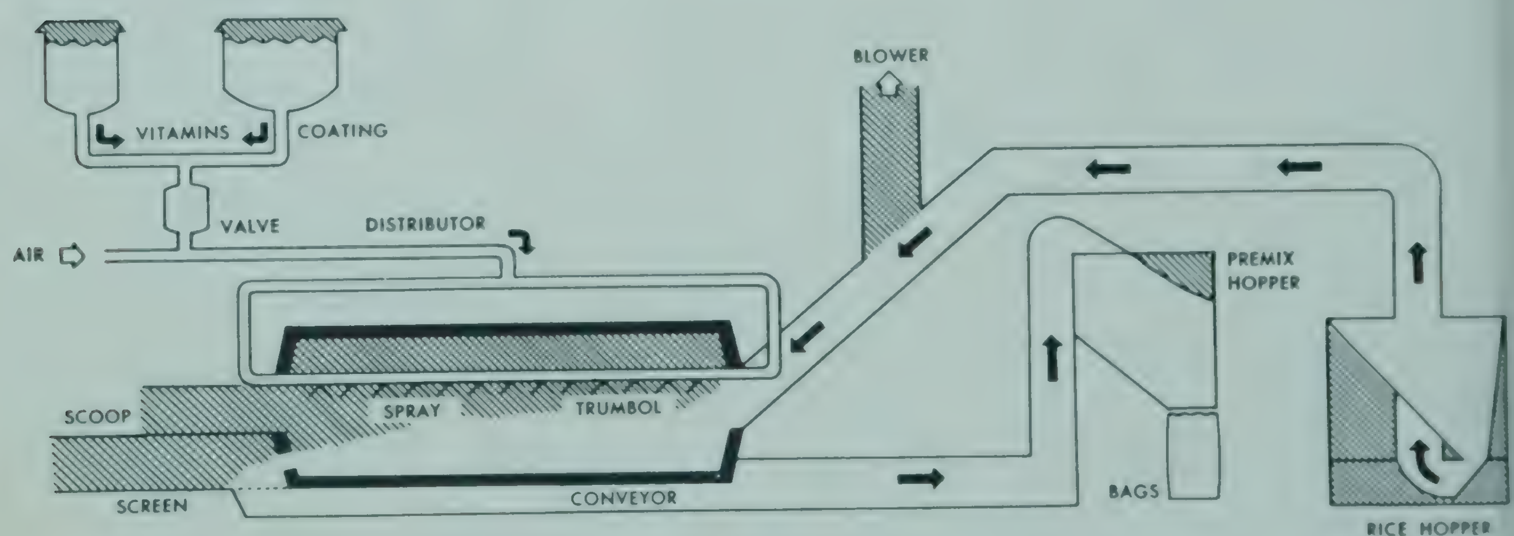
Although South Carolina is the only state of the Union where sale of en-

riched rice is mandatory, the importance of this more nutritious form of the cereal is considered great enough that standards for enrichment are being set up by the Food and Drug Administration of the Department of Health, Education, and Welfare.

Rice may be enriched in various ways. The parboiling of rice is actually equivalent to an enrichment process because during the soaking and cooking of rough rice, bran vitamins diffuse into the endosperm. And so in areas where parboiled rice is consumed as the main form of this cereal, the population receives a satisfactory dosage of these nutritional elements.

Artificial enrichment usually consists in heavily fortifying small quantities of milled rice with thiamin, niacin and iron phosphate to make what is known as "premix." Riboflavin is not generally added because it turns the grains yellow. This highly enriched rice is then diluted with 199 times its weight of unenriched rice to make a blend containing the enriching vitamins and iron at slightly above the level present in brown rice.

In making premix, the iron and vitamins are built up on the grains in layers and protected with an edible coating. Such a product will pass the washing test required in the Puerto Rican law.

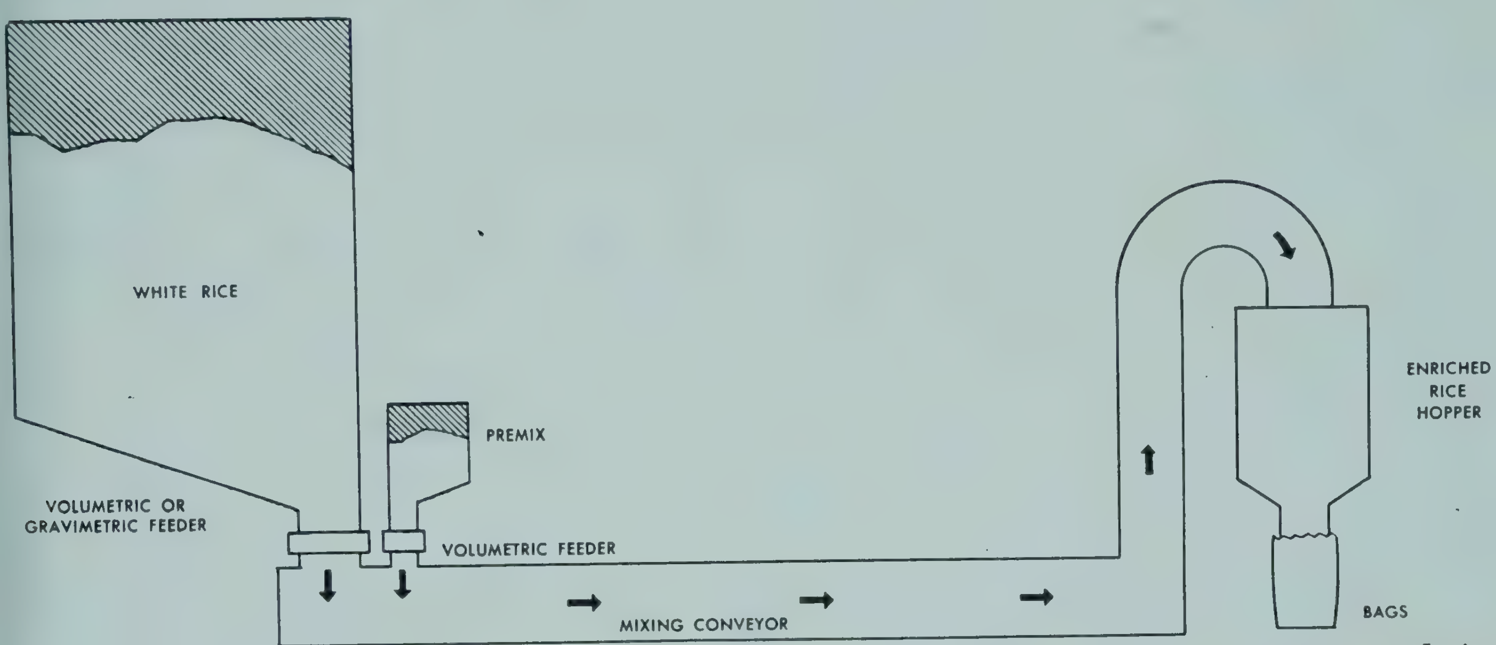


Courtesy of National Vitamin Foundation

FIG. 113. DIAGRAM SHOWING PRODUCTION OF RICE PREMIX

Premix is made by two quite similar processes. In one, which is representative (Furter and Lauter 1946; Mickus 1955), a 2150-lb. lot of milled rice is charged into a trumbol fitted with baffles (Fig. 113). A vitamin solution made up of 39.5 lbs. of niacin, 6 lbs. of thiamin, 21 lbs of sulfuric acid, and 58 lbs. of water is fed into the trumbol by a perforated stainless steel pipe that runs full length of the unit. In about ten miuntes the rice grains are uniformly coated with the mixture, and air is then blown into the trumbol to dry the coating so that the grains are free flowing. Next, half of an enrobing solution consisting of 13.75 lbs. of abietic

acid, 16.25 lbs. of a solid fatty acid, 20.25 lbs. of zein, 18 gallons of isopropyl alcohol, and 1 gallon of water, is sprayed on the rice and similarly dried. Open scoops containing 270 lbs. of dry ferric pyrophosphate with 405 lbs. of talc are then run into the trumbol and inverted, and after the solid material is well dispersed over the rice, the second half of the enrobing solution is applied. With these proportions of ingredients, the final product has a content per pound of 440 mg. of thiamin, 3,200 mg. of niacin, and 2,600 mg of iron. The premix is diluted incrementally with 60-lb. quantities of untreated rice in the 1:199 ratio by proportionation weighing (Fig. 114).



Courtesy of National Vitamin Foundation

Fig. 114. Diagram of Blending of Premix with White Rice

The quantities of enriching agents specified in the above description apply only to one procedure commonly used in the United States. In the Far East where rice enrichment is practiced, different amounts of vitamins are used, and the composition of the coating solution is modified to meet specific local needs, both nutritional and environmental.

To give the grains of enriched rice a whiter appearance than formerly, and to permit addition of riboflavin (in spite of its yellow color) to the enriching mixture, the protective coating may contain white pigments such as calcium phosphate, talc, and titanium dioxide according to recent patents (Antoshkiw 1958; La Pierre 1955).

A simpler one-step process of enriching rice is also practiced. In this process, the powdered fortifying ingredients are merely tumbled with dry rice until they are uniformly distributed over the surface of the grains to which they cling with considerable tenacity. Such a coating, however, would not be expected to pass a washing test as specified in the Puerto Rican law. In other localities where this form of enriched rice is sold, precautions against rinsing the rice before cooking appear on the package.

THE FUTURE OF RICE PROCESSING

Current practices and research concerned with rice processing and products indicate an active interest on the part of both consumers and technologists in this interesting cereal and what can be done with it to enhance its appeal or make it more useful. The imaginative thinker can set down numerous possibilities where rice might be used as a raw material. He must, however, be realistic and ask himself whether the products he envisions, edible or inedible, could not be made just as well from lower priced grains. The economic factor in many instances will rule out rice for specific purposes. Thus, it is improbable that rice will compete on a broad front with other starchy grains in the non-food field. Nevertheless, it does possess certain inherent characteristics that are unique such as its whiteness and the extremely small size of its starch-granules that may be important in specific applications. As a food-stuff it has qualities which have made it preferred to wheat as a basic commodity in the diet of vast population groups despite its higher cost. This preference for rice in such areas is probably due to factors other than long standing food habits. Just as rice has attained a strong position in the formulation of baby foods, it may also become important in geriatric feeding which becomes increasingly important as the span of human life advances. The trend toward improving the nutritional value of foods is growing. Progress has been made in the enrichment of food stuffs such as rice and flour, but much remains to be learned about supplementation and advances in our knowledge of this subject are certainly in the offing. Rice processing for various purposes has, therefore, a bright future, and the years ahead will doubtless be fruitful ones for this important crop.

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E. J. Abeling

Manufacture of Special Dietary Foods

Consideration of special dietary foods in the cereal class includes those designed and developed for infant and geriatric feeding. The first of these special foods was developed years ago by a physician who used the product in an orphanage where there was definite need for a highly nutritious food. The product was a dried pre-cooked cereal containing added vitamins and minerals for babies. Since that time, baby food companies producing infant cereals have followed this pattern, and include several varieties in their line. Some of these are **oatmeal, mixed cereal, barley cereal, corn cereal, rice cereal,** and **hi-protein cereal.**

These products are derived from single grains or blends of mixed grains combined with other ingredients for flavor and nutritional fortification. Materials used by various manufacturers, in addition to the grains, include malt, milk solids, vegetable oil, wheat germ, sugar, cottonseed flour, tri- or dicalcium phosphate, dried yeast, a form of iron such as sodium iron pyrophosphate, and the B vitamins—thiamin, riboflavin and niacin. The formulas and manufacturing procedures are carefully controlled so that the vitamins and minerals are present in sufficient quantity to satisfy certain label declarations.

Infant cereal labels, in most instances, list a complete proximate analysis as well as a section stating the percentage of minimum daily requirements for some of the vitamins and minerals present in a certain portion of the product. An example as taken from a leading baby food manufacturer's label for **oatmeal,** is shown in Table 84.

It is interesting to observe the development process of a new baby cereal product. Since such products are the baby's first solid food, they require very special treatment. In formula development, therefore, the following factors are usually given primary consideration:

(1) allergenicity of the various ingredients; (2) compatibility of the mixed materials to give desired flavor and appearance in end product; (3) availability of raw materials used; (4) nutritional aspects of the formula; (5) stability of the formula (shelf life); and (6) ease of manufacture.

The period of development for an infant cereal may extend from a few

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FIG. 115. COLORFUL PACKAGES HELP SELL INFANT CEREALS

TABLE 84

APPROXIMATE ANALYSIS OF OATMEAL CEREAL

Protein (N × 6.25), per cent	16.5
Carbohydrates, per cent	63.3
Fat (acid hydrolysis), per cent	7.0
Ash (total minerals), per cent	5.7
Crude fiber, per cent	1.3
Moisture, per cent	6.2
Calcium, per cent	0.8
Phosphorus, per cent	0.9
Iron (Fe), per cent	0.05
Calories per avoir. oz.	108
Thiamin (B_1) mg. per oz.	0.46
Riboflavin (B_2) mg. per oz.	0.45
Niacin, mg. per oz.	1.00

One ounce of **Oatmeal Cereal** supplies the following proportions of the minimum daily requirements of each vitamin and mineral named, as established by the U. S. Food and Drug Administration.

	Infants (to 1 yr.) Per cent	Children (1–6 yrs.) Per cent
Thiamin (B_1)	184	92
Riboflavin (B_2)	90	[1]
Iron	[1]	187
Calcium	[1]	29
Phosphorus	[1]	33

[1] Minimum daily requirement not established for ages indicated.

TABLE 85

SPECIFICATIONS FOR OAT FLOUR

Product

Product obtained by the processing of cleaned, hulled oats under strictly sanitary conditions and in accordance with good commercial practice.

Analysis	*Per cent*	
Protein	16 to 17	Range jointly agreed upon by supplier and packer
Ash	1.5 to 1.7	
Fat (acid hydrolysis)	7	
Fiber	1.4 to 1.7	
Moisture	8 to 9	

Properties	*Requirements*
Visual	____Free of foreign matter
Odor	____No off odor
Flavor	____No off flavor

Deliveries

All deliveries must conform in every respect to the requirements of the Federal Food, Drug and Cosmetic Act, as amended and regulations promulgated thereunder, and to the requirements as given under the properties section of this specification.

In addition, deliveries must be guaranteed free from contamination or infestation of any kind. Shipper shall be responsible for the proper selection of clean cars and trucks transporting this material.

Containers

Shall be packed in clean, new multiwall paper bags adequately closed, free from foreign matter, clearly labeled and when packed shall contain 50 lbs. of **oat flour** net weight.

months to as long as 2 or 3 years depending on the problems encountered, and may vary in accordance with the requirements and policies of the various manufacturing companies.

Since the end product can only be as good as the materials which make up its composition, the raw materials used in manufacturing infant and geriatric cereal foods must be of high quality.

Only reliable suppliers who have previously been established as satisfactory sources of supply can be used. Specifications, based on the intended use of the ingredient in the product, are furnished to the supplier. He, in turn, submits a sample of the material for the cereal manufacturer's evaluation, if he believes it meets the specifications.

There are numerous points included in a set of specifications, depending upon the material. Grains and flours contain in their specifications a definition of the material, sieve size or screen size, certain nutritional and analytical requirements, a description of the desired properties, the type of container to be used, cleanliness of railroad cars or trucks, and a statement to the effect that the material deliveries must comply in every respect to the requirements of any regulatory agencies and must be free from rodent or insect contamination. On the other hand, specifications for ingredients such as the vitamins or minerals include mainly the re-

TABLE 86

SPECIFICATIONS FOR CORN FLOUR

Product

Product to be of the degerminated type, milled from yellow shelled corn. The corn used is to be clean, sound, and free from seeds, weeds, other grains or foreign material, shall conform with U. S. Official Federal Grain Standards, and shall be milled to meet Federal Standards of Identity for degerminated corn flour and Pure Food and Drug specifications.

Analysis

	Per cent	
Protein	6 to 7	Range jointly agreed upon by supplier and packer
Fat (acid hydrolysis)	2.0	
Crude fiber	0.5 to 0.8	
Ash	0.5	
Moisture	10 to 11	

Deliveries

Deliveries against this order must be guaranteed free from contamination or infestation of any kind. Pesticide residues must not exceed limits established by federal tolerance. Shipper shall be responsible for the proper selection of clean cars and trucks transporting this material.

Product is to be packed in 50-lb. multilayer paper bags.

TABLE 87

SPECIFICATIONS FOR BARLEY FLOUR

Product

Product to be directly milled from whole grain barley into the flour state. It shall be cleanly milled, free from foreign particles, contamination or infestation of any kind, and shall comply with all Food and Drug specifications.

Analysis

	Per cent	
Protein	11 to 12	Range jointly agreed upon by supplier and packer
Fat (acid hydrolysis)	3.0	
Moisture	11 to 12	
Crude fiber	0.5 to 1.0	
Ash	1 to 1.5	

Deliveries

Deliveries against this order must be guaranteed free from contamination or infestation of any kind. Pesticide residues must not exceed limits established by federal tolerance. Shipper shall be responsible for the proper selection of clean cars and trucks transporting this material.

Product is to be packed in 50-lb. multiwall paper bags.

quired grade and potencies. Typical specification sheets for various grains and flours are shown in Tables 85, 86, 87 and 88.

As raw materials are received at the manufacturer's plant, representative samples are drawn from each lot and examined. This is to determine whether the material meets specifications and whether it will be satisfactory for the product. An important factor kept in mind is the declared values on the labels of the end product making it doubly important for the raw materials to meet the requirements.

Among the routine tests run on samples of incoming lots of flour and grains by the quality control laboratory are:

TABLE 88

SPECIFICATIONS FOR WHEAT FLOUR

Product
Product to be obtained by milling clean, soft winter wheat under strictly sanitary conditions and in accordance with good commercial practice.

Analysis	*Per cent*	
Protein	8 to 9	Range jointly agreed upon by supplier and packer
Ash	0.40 to 0.50	
Fat	..	
Crude fiber	0.3 to 0.6	
Moisture	12 to 15	

Properties	*Requirements*
Color	____White to light tan
Visual	____Free of foreign matter
Odor	____No off odor
Flavor	____No off flavor

Deliveries
All deliveries shall comply in every respect to the requirements and provisions of the Federal Food, Drug and Cosmetic Act as amended, and regulations promulgated thereunder.

Containers
Shall be packed in clean, new 50 lb. net weight multiwall paper bags. Shipper is responsible for the selection of clean railroad cars or trucks.

1. Insect Counts.—Insects and insect fragments are extracted from a weighed portion of material with special techniques and equipment, and counted by microscopic examination. Values are reported as number of fragments per 50 or 100 gm.

2. Visual Examination.—Materials are visually examined for color, speckiness, and foreign matter. Railroad cars or trucks in which the material is shipped are also inspected.

3. Proximate Analysis.—Official chemical methods are used to determine amounts present in each of the following: protein, ash, crude fiber, moisture, and fat. Materials other than the grains and flours such as milk solids, dried yeast, wheat germ and others may be checked for certain specific things such as protein content, fat content, and certain mineral values.

When raw materials received do not meet specifications, rejections are made by the laboratory and the shipment returned to the supplier. Knowing this, suppliers are very careful to ship only lots of material they feel will meet the standards and rejections are seldom necessary.

As raw materials are received, they are placed in proper storage areas. These areas must be clean and dry, rodent proof, of proper temperature, and free of infestation. Materials should be placed on pallets at least 18 inches away from the wall to permit inspection. Not all raw materials used in the manufacture of these special cereals require the same storage

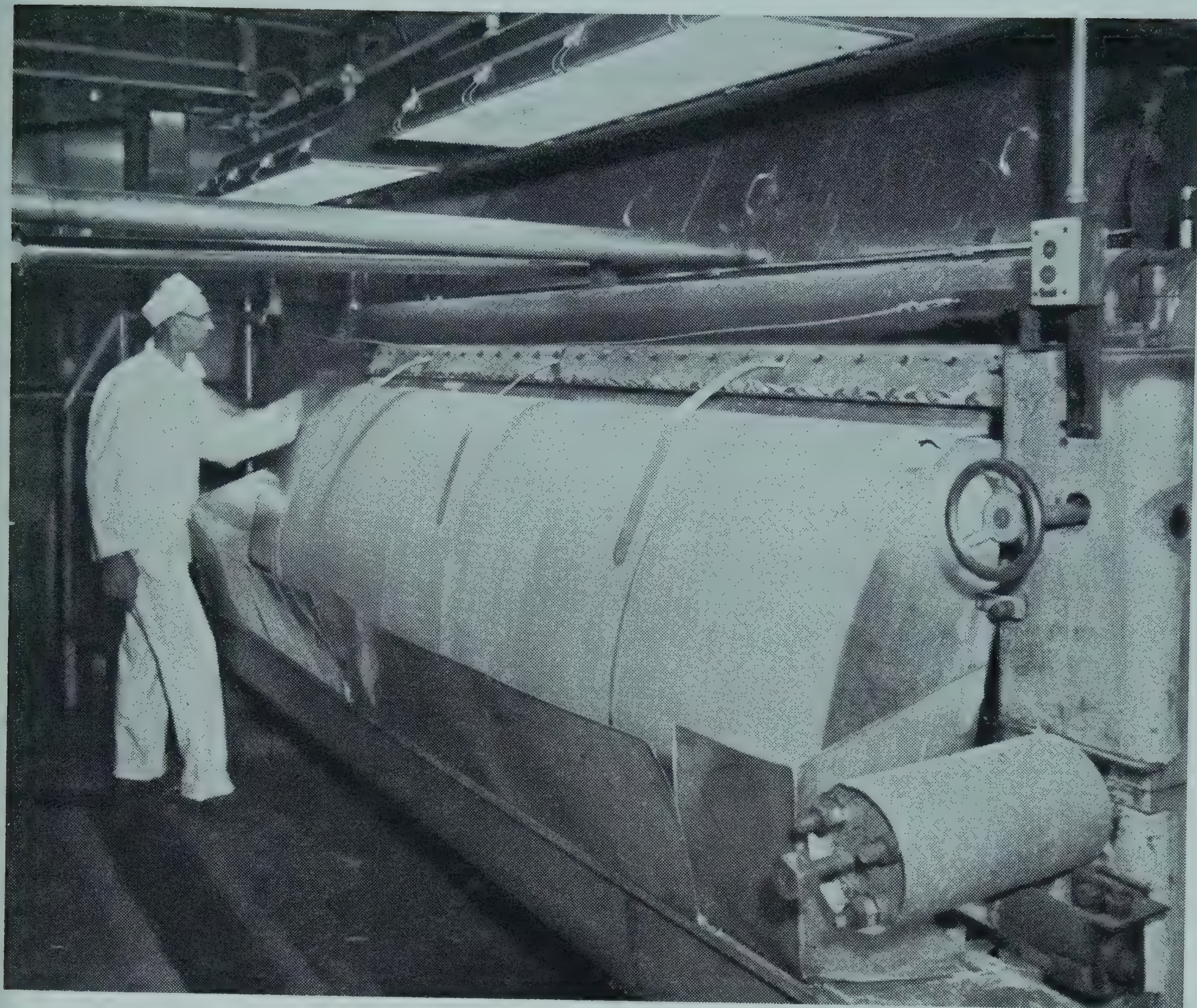

FIG. 116. DRUM DRIER FOR INFANT CEREAL

temperature. Some are satisfactory at room temperature while others should be stored at 45° to 50°F. It is important to control inventories since lengthy storage can sometimes be detrimental to certain ingredients.

Once raw materials have been approved for use, production of the cereals can begin. In the cereal ingredients room, those materials used in small amounts per batch are carefully weighed, placed in a small container and identified by product name and batch number. It will contain the minerals, vitamins, salt, and other minor ingredients.

Approximately 150 gallons of water is drawn into a mixing tank. With the agitator in motion, the amount of grain and flour per batch is sifted into the tank along with the contents of the container referred to above making a slurry of 300 lbs. of dry material to 150 gallons of water. At this point, the batch may be pumped to a pressure kettle where it is completely cooked (for example, 10 to 20 minutes at atmosphere or under pressure) or it may remain in the original kettle where a similar or longer cooking process takes place.

After cooking is completed, the batch of cereal is pumped to atmos-

pheric drum driers. This piece of equipment is composed of a set of rotating hollow steel drums, heated internally. The length of time neces-

WEIGHING OF INGREDIENTS

↓

SIFTING

↓

BLENDING KETTLE

↓

COOKING KETTLE

↓

DRYING ROLLS

↓

FLAKING MACHINE

↓

PACKAGING LINE

↓

AUTOMATIC CASER

FIG. 117. FLOW DIAGRAM FOR INFANT CEREAL PRODUCTION

sary to pump out a complete batch of cereal varies according to the drying capacity or rate of the cereal. This ranges (according to the variety of cereal) from 20 to 40 minutes. The cereal is pumped between the two drums which dry the product in a thin sheet as they rotate. The sheets are removed from the rolls by knife blades and conveyed to a flaking machine. Here the sheets are broken into small flakes which vary in

size, depending on cereal variety and manufacturer. At this point, the flaked cereal may be conveyed directly to the packaging line or placed in clean storage drums for later packaging.

Modern packaging lines can be equipped to accomplish a multiple operation. They may assemble the package and seal the bottom, insert a pouring device, fill the box with product, seal the top and in some cases, wrap the package.

Fig. 117 is a flow sheet of a cereal production line.

Variations of the general description just given occur between manufacturers. Since formulas for a given product are different, according to the brand, there will necessarily be some differences in the manufacturing methods. The first step of weighing and blending is fairly standard.

The cooking procedure may vary however, in temperature, length of cook, and amount of water used. The characteristics of the cooked cereal influence, of course, the drying process. Temperature and speed of the drier rolls may be adjusted and these variables also affect the product produced. For example, the thickness of the sheet of cereal as removed from the drier roll influences the reconstitution properties of the finished cereal, the volume for packaging, and the texture of the end product. The size of flake may have the same effects.

Color and flavor of the end product may be influenced by length and temperature of cooking as well as drying. Variation in drying can also affect the moisture content of the end product which should be carefully controlled.

Sanitation of production areas is just as important as specified for storages. Modern plants have vacuum cleaning systems installed, particularly in drying and packaging areas. Infestation must be carefully watched and proper control methods maintained.

Rigid quality control, both "in process" and on finished product is followed in packing cereals for babies and for geriatric use. During manufacture, the process is carefully followed by quality control personnel usually assigned to a specific area. Some manufacturers go so far as to have the vitamin and mineral ingredients weighed by laboratory personnel. Constant checks are maintained on processing conditions while the cereal is "in process."

At the packaging line, weights are checked at regular intervals and packages examined to determine whether a satisfactory job has been done. Required adjustments are made on the spot.

The finished product itself receives elaborate attention from the quality control laboratory. Representative samples are drawn from each run and a complete proximate, vitamin and mineral analysis conducted. This is done to insure that the label declaration has been satisfied. Testing

is conducted in accordance with official methods, most of which are chemical, although in the case of the vitamins, microbiological techniques are sometimes used.

Fig. 118. Final Inspection of the Package of Baby Cereal

In addition to routine checks for label information, the following functions are usually performed at regular set intervals during a production run:

1. Insect Counts and Examinations for Foreign Matter.—These are not mere visual examinations. Samples are subjected to elaborate extraction procedures after which the recovered material (if any) is retained on a filter paper and carefully examined with a microscope. Trained

technical personnel conduct these tests and report their findings immediately.

2. Appearance.—Samples are spread out on special trays and visually examined for signs of lumps, scorched particles, color, and flake size.

3. Reconstitution Properties.—Directions are sometimes given on the label for suggested proportions of cereal to liquid when preparing the product for feeding. Warm milk may be used for mixing with the cereal to test its characteristics in this respect. Uniformity should be maintained, and the product should reconstitute with ease.

4. Flavor and Texture.—While the cereal is in process, constant tests for flavor and texture are made by quality control personnel. Deviations from the normal must, of course, be immediately corrected. Following this, samples are submitted on a daily basis to larger groups making up a taste panel. The primary purpose of this panel is to judge whether the product is within normal range of flavor and texture for the particular product. Accurate records are maintained.

5. Net Weight and Fill of Container.—Here again, it is necessary to keep a constant check since there is the possibility of variation due to some of the following: (a) filling machine adjustment; (b) package variation; and (c) characteristics of the product.

Weighing devices are usually installed in the packaging line with an inspector carrying out this function. In addition to this, however, sample packages may be withdrawn from the line, brought to the laboratory and examined both for net weight and fill of container.

Table 89 shows a typical form used to record daily quality control data.

6. Reference Samples.—Some laboratories have adopted the practice of drawing several sample packages daily during packing operations and retaining them as shelf samples for future reference. These are often valuable as representative samples of the run.

7. Trade Samples.—It is a practice with some quality control laboratories to periodically sample the product in distribution. Trade samples may be sent into the laboratory from various sales areas for a check on product and package.

8. Competitive Testing.—One of the major points of interest in marketing a food product is its rating as compared to the competition. This is especially true in the field of special dietary foods, particularly baby foods, which represent a highly competitive market. It is, therefore, good practice to make comparisons with competitive products at regular intervals. To avoid bias or unfair comparisons, all samples (the product and its competitors) should be obtained from retail outlets. This may be done through the sales department whose personnel can purchase the products and send them to the laboratory.

Table 89

DAILY QUALITY CONTROL RECORD

Product__________________ Date______________

	Per cent
Protein	________
Carbohydrate	________
Fat	________
Ash	________
Crude Fiber	________
Moisture	________
Phosphorus	________
Iron	________
Calories	________ Per oz.
Thiamin	________ Mg. per oz.
Riboflavin	________ Mg. per oz.
Niacin	________ Mg. per oz.

Time of Sample	Insect Count No./50 gm.	Appearance	Flavor and Texture	Reconstitution Properties	Net Weight	Per cent Fill

There are several methods that can be used to run comparisons by panel testing and undoubtedly these are in use in various laboratories. One method is described as follows:

The technician conducting the test marks the samples with a code so that only she knows the identity of the samples. Weighed portions of cereal are placed in bowls marked with the same code. Measured portions of warm milk are added to obtain the correct ratio of cereal to liquid and then mixed. Portions are presented to the panel tester marked by code so that he does not know which brand he is testing. Along with the samples to be tested, he is given a ballot on which to record his evaluation. The tester merely checks the rating which he feels applies for each sample. In evaluating results of panel tests, it is well to assign a numerical rating to each of the categories listed (excellent, good, fair, and poor). By this means, each sample evaluated receives a numerical value and the final comparisons are more meaningful.

Panel testing should be conducted in a separate room equipped with special facilities. Some of these are:

1. Air conditioned and not subjected to odors. It has, of course, been established that there is a close relationship between taste and odor so that an interference of this type could influence the tester's judgment.

2. Special lighting. When two or more samples vary in color or appearance, the tester is influenced. To avoid this, red lights may be used which rule out these differences to a great extent.
3. Separate booths for each tester. This eliminates distractions, and permits concentration on the test.

Panel members need not necessarily be exclusively laboratory personnel. They may be drawn from various sections of the company such as offices, sales department, and production department and should be considered a consumer panel.

It may be seen from this description of the quality control program that should be maintained in producing these special cereal products that a good technical department is necessary. The procedures and methods used require a well equipped chemical laboratory and a well trained staff. The size of the manufacturing operation and the number of products produced can determine how large a laboratory staff is needed but most of the laboratory facilities are needed whether the operation is large or small.

As previously stated, these special cereals were developed for a specific purpose and were fortified with certain vitamins and minerals. Infant cereals today are fortified with calcium, phosphorus, and iron and vitamin B complex. Amounts added furnish significant percentages of the minimum daily requirement per ounce of product. Many pediatricians feel that the iron and B vitamins contribute certain essentials to the diet (Sniveley and Lynch 1953) and are the most valuable of the additives. Calcium is not required as much by the artificially fed baby as it is by the breast fed baby where supplementation may be useful (Jeans and Marriott 1947). Since these cereals are usually the baby's first solid food, it is well that these fortified products are available.

By far, the largest portion of these products are purchased for feeding babies. One of the purposes of adding solid food to the baby's diet is to acquaint him with foods of a different consistency, texture and taste than those of liquids. Cereal is usually the first solid food offered and due to its convenience has many advantages to the mother. They can be fed without waste in any amount desired and since they are pre-cooked are easily prepared for feeding.

Addition of cereal to the infant's diet occurs at about the third month (Jeans 1950). Only small amounts are used at the start, gradually increasing as the infant grows older. Mothers usually follow the pediatrician's advice as to when cereal feeding starts and oftentimes begin with a single grain cereal rather than a mixture. This is particularly true if there is a history of allergies in the family and the pediatrician wishes to avoid mixtures at the start.

In many cases, these special cereals are used by older children since they make an excellent hot cereal and are so easily prepared.

The most extensive use other than for infants is undoubtedly by older people. These people, many of whom live alone on limited incomes, find a fortified, convenient food of this type extremely appealing. No elaborate facilities are needed to prepare them and they are economical to use.

Pre-cooked infant cereals also have other uses, particularly in special diets, some of which are: (1) soft diets following disease or surgery; (2) diet following dental extraction; (3) diet for gastro-intestinal diseases; (4) ulcer diet; (5) low sodium diet (some varieties only); and (6) special allergy diets (single grain varieties). Many consumers have found uses for these products in recipes and some delicious cookies, muffins, and desserts can be made with them. They have been found useful as thickening ingredients for soups, sauces, and meat loaf.

Modern infant cereal products have come a long way from the early concepts of the baby's first solid food, and are accepted today as a regular part of the infant diet.

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Paul R. Witt, Jr.

Malting

INTRODUCTION

The process of malting consists of the controlled germinating and, usually, the subsequent drying of a seed. The seed most generally used is barley, although small quantities of wheat and rye are also processed.

This chapter discusses the purposes of malting and the physical means employed to induce the change in the properties of the kernel which maltsters refer to as modification. While the term "modification" has been associated with the physical properties which characterize a good malt, it definitely includes all those changes in colloidal state and chemical composition which the constituents of barley undergo during malting. These changes are not confined to the germinating period but continue during the early stages of kiln drying and they markedly affect flavor, color and a number of aspects of chemical composition. The conversion of grain to malt is essentially physiological in nature and is a result of the action of enzymes.

In the subsequent discussion, the emphasis will be placed on malting practices in North America and specifically in the United States, unless otherwise noted. Reference will be made to malting barley varieties, mechanical means for preparing the barley for malting, the actual steps of processing, the variations in processing which affect quality and the merchandising of malt as related to process methods.

BARLEY VARIETIES

Generally speaking, commercial malt as it enters channels of distribution consists mostly of the variety Kindred or of a blend of several varieties in which Kindred is predominant. In the 1958 crop year there was produced a large acreage of the variety Traill which is acceptable as a malting barley. It is difficult to distinguish Traill from Kindred and no effort is being exerted to separate them in the commercial marketing of the present crop.

Malt is blended to satisfy individual specifications and the varieties usually requested in addition to Kindred are Montcalm and Hannchen or Hanna. The latter are two-row varieties and are frequently included to

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serve as extract boosters. Some consider their admixture as a factor contributing flavor and/or foam sustaining characteristics.

Kindred is mainly grown in the Red River Valley of North Dakota and in southwestern Minnesota and northeastern South Dakota. It is a white aleurone barley with relatively high potential enzymatic activity and it modifies well during malting. Barley selected for malting is usually within an approximate protein range of 12.0 to 13.5 per cent. However, satisfactory malts have been prepared from grain beyond these limits.

At present, almost all of the Montcalm originates in the prairie provinces of Canada. It is a blue aleurone barley usually of lesser enzymatic activity than Kindred and lends itself well to modification. The approximate protein range observed for good to satisfactory malting barley has been 11.5 to 13.5 per cent.

Hannchen is grown in the Klamath and Willamette Valleys of California and Oregon, while most of the Hanna is produced in the Palouse and Camas areas of Idaho.

Both are converted into mellow and well modified malts. During the past several years, Canada has exported Hannchen to the United States. Due to cheaper transportation by water, the Canadian Hannchen is less costly and sound barley of this type results in malt of satisfactory modification.

The variety Atlas, relatively low in laboratory-determined enzymatic activity, is grown and malted in California and in a small area of Mexico. When used in brewing, it is generally mashed in conjunction with Midwestern malt (Kindred or a mixture of Kindred and Montcalm).

A review of other barleys used in malting includes Olli (Canadian origin), O.A.C. 21 and the varieties which have recently presented themselves—Traill, Parkland and the two row Betzes.

A more complete description of the agronomical and morphological aspects of barley varieties is included in Chapter 4 entitled **Barley.** Additional details can be found in "Classification of Barley Varieties Grown in the United States and Canada in 1945" and "Barley Variety Dictionary" (Anon. 1957).

Requirements governing commercial trading of barley are listed in the "United States Official Grain Standards" (Anon. 1957A). Additional information is available in the "Western Canada Grain Grades" (Anon. 1926).

PREPARATION OF BARLEY FOR MALTING

The process of readying barley for malting can be separated into several steps. The first step is basic and reflects itself in procurement. Maltsters and some of the grain merchandising houses conduct field studies of the

barley crop before harvest. Knowledge thus gained provides the buyer with information as to origin of sound and plump grain.

Soundness is an expression which in its strictest sense means viability or germinating capacity, but it has been augmented to include relative freedom from mold or mold damage.

Total protein content is also determined as extensively as sample accrual and laboratory facilities permit. The resulting data can be arranged as a varietal-origin-protein map and the maltster can resolve his storage or binning program with respect to arbitrary ranges within a variety.

As a result of practical experience and from knowledge gained by pilot or experimental malting, the maltster can establish an area of demarcation where perhaps all samples analyzing 12.8 per cent or under will qualify as "low" protein and those above as "high." A statistical mean is not necessarily the most desirable way to set up limits between lots of barley. While the degree of modification of malt is obviously related to the crop year, adaptability of a barley type to the individual physical plant and to the methods of malting is more important when segregating according to protein content.

In years when growing conditions have been affected by considerable local variations in weather, maltsters have sought to achieve malt uniformity by binning and malting selected protein ranges of a definite variety originating in distinct growing areas. For example, in some years it has been found that mature Kindred barley of 12.8 to 13.2 per cent protein originating in the Red River Valley in the general vicinity of Fargo, North Dakota, modified more readily than comparable Kindred of 12.3 to 12.5 per cent from an area adjacent to Bismarck, North Dakota, where drier weather conditions are frequently experienced.

Generally speaking, it is thought that barleys of lower protein content modify more readily.

Dormancy and "newness" are factors to be considered when readying barleys for malt processing. True dormancy, which is revealed by the lack of response to germination by sound barley, is thought to be related to variety, geographical origin and to drying and/or earliness of harvest. Dormancy has been shown to be related to the accessibility of oxygen to the embryo. The causes of dormancy in seeds have been studied by Crocker (1916), Gracinin (1928), Deuber (1931), Flemion (1934) and Brown (1933) and they have suggested physical and chemical methods of overcoming dormancy. In the malting laboratory, dormancy is generally surmounted by steeping or soaking in 0.2 to 0.5 per cent hydrogen peroxide, subjecting to cold (45° to 55° F.) storage as dry or as steeped grain and by scarification or physical abrasion.

In practical operations, dormancy has been treated by washing the barley in lime water, rinsing with water and then adding water acidified to pH 2.5 with sulfuric acid. The steeping barley is agitated with compressed air or other mechanical means and the acidified water decanted after three to five hours.

Custom in the malting industry has demanded that barley "go through the sweat" prior to qualifying as ready for malting. Since good practice demands selection of grain which is dry and since barley is freed from contaminating seeds and foreign material which may still be green (weeds, etc.), very little if any actual sweating is observed in present-day "terminal" barley storage.

Yet, sound barley will still produce undesirable malt if malted too soon after harvest even though it may germinate vigorously and uniformly. Undermodification and hazy laboratory worts frequently characterize malts prepared from immature barley.

Sound and bright Kindred barley when malted under comparable conditions at different times after harvest yielded malts whose quality characteristics are described in Table 90.

TABLE 90

EFFECT OF PROGRESSION OF MATURATION OF NEW CROP BARLEY ON MALT QUALITY

Steep Date	Germination Per cent	Extract Per cent	Soluble/ Total Protein Per cent	Wort Clarity
Aug. 21	97	72.5	35.5	Hazy
Sept. 21	99	73.5	37.5	Slightly hazy
Oct. 15	99	74.3	39.2	Clear

In all probability, the "sweat" period customarily referred to is in actuality an "after-ripening." Eckerson (1913) studied microchemically the alterations accompanying the after-ripening of seeds and noted that the initial change in embryo was an increase in acidity. This was correlated with an increased water-holding capacity and an increase in the activity of catalase and peroxidase. Near the end of the after-ripening period there was a sudden increase in acidity and in water absorbing ability and oxidase made its first appearance.

In actual commercial practice many maltsters accept as a rule the deferment of malting "new" crop barley until about October 15.

CLEANING AND GRADING OF BARLEY

It has been noted that accepted practice demands that each barley variety be stored separately and that types within a variety be segregated

as to protein level and in some instances as to geographical origin; that barley must be dry (under 14 per cent moisture) at time of storage and that it be cleaned of dust and weed seeds of high moisture content before binning.

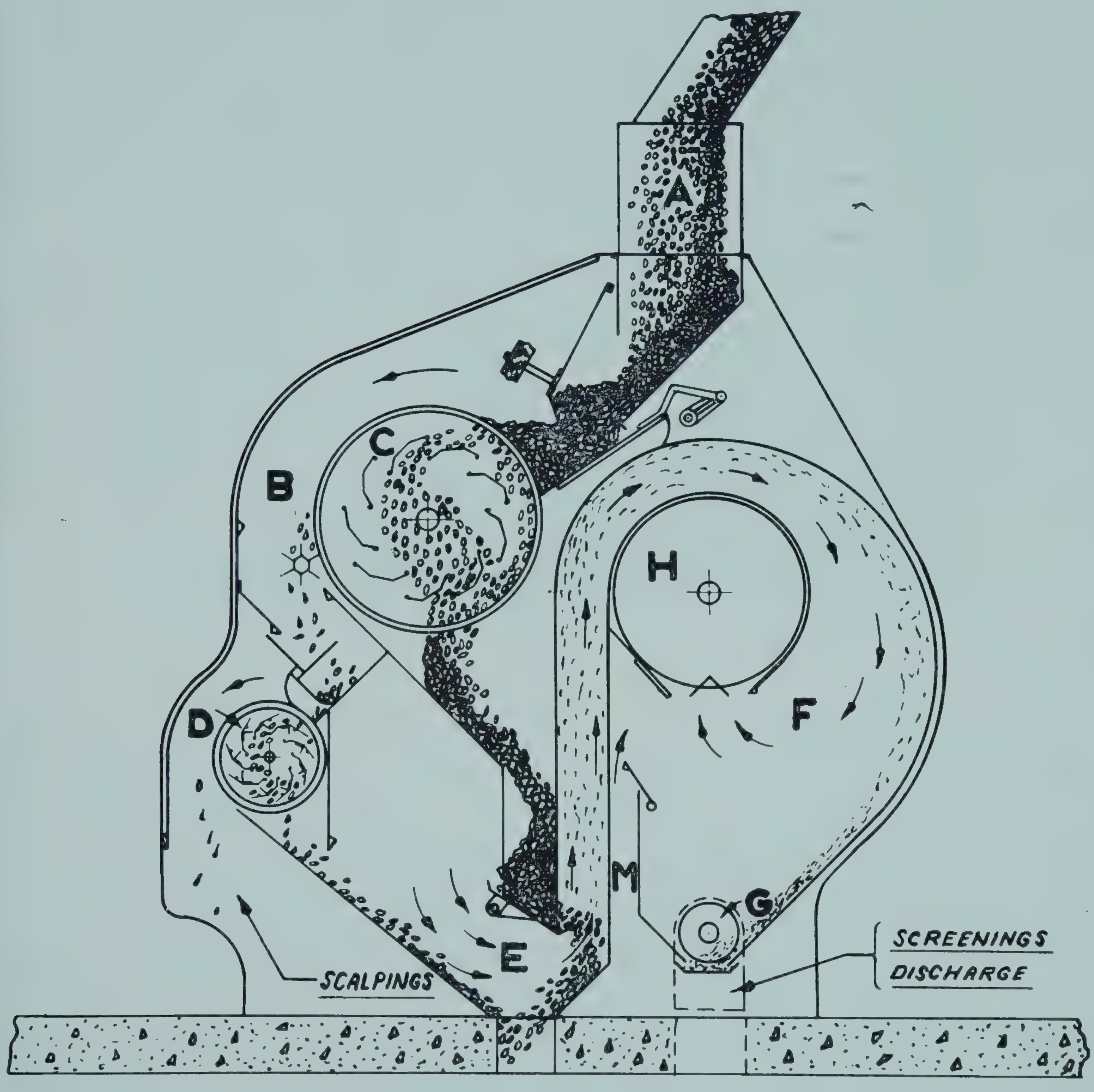


Fig. 119. Cleaning and Grading Barley Prior to Malting

The act of grading or kernel sizing prepares the barley for malt processing, the initial step of which is steeping or soaking. Barley is classified as to kernel size or shape primarily to assure uniformity during the malting process. It is probably coincident to the barley grading that the price structure governing the marketing of malt has been established.

To demonstrate barley grading, a flow sheet of one possible procedure is outlined in Fig. 119. Barley as harvested, known as "country-run," enters a scalping machine at (A) from the bin, and is fed at the desired rate to the scalping reel (C) which removes sticks, straw, nails and other

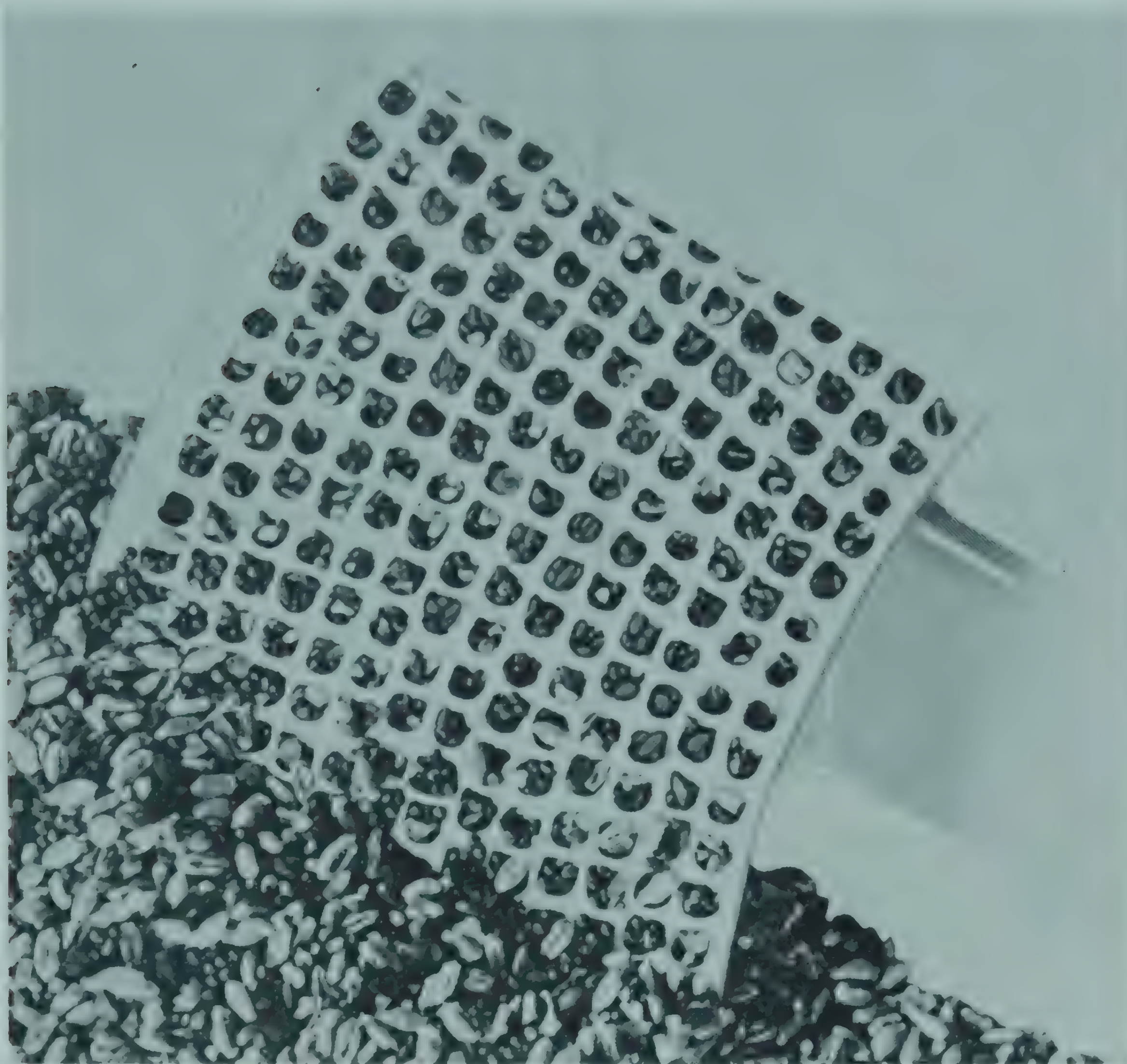


FIG. 120. SECTION OF A CARTER DISK

roughage. Roughage is then carried over at (B), to the rescalping reel (D). Aspiration takes place at (E), where the grain leaves the seal gate in an evenly spread stream through which a current of air is drawn. The light screenings are carried up the aspirating leg and the heavier grain drops back into the main grain stream, thus effecting light screenings removal. The air from settling chamber (F) is drawn into the fan through inlet (H). The fan exhausts into a dust collector. Rapid expansion of air in the settling chamber (F) allows screenings to drop to the bottom where they leave the machine by screw conveyor (G). The volume of air passing through the grain at (E) may be controlled by adjusting the by-pass valve (M) through which air enters the suction tube directly.

To achieve a more thorough cleaning, grain from the Scalperator may may be permitted to pass through a Eureka-type cleaner. "Country-run" grain may also be passed directly to this machine.

The Eureka-type cleaner consists of parallel sieves with a flat plane surface, placed at a slight angle to the horizontal, permitting the grain to flow downward. The sieves are fixed to wooden or steel frames and are oscillated by means of eccentrics on a driving shaft. Series of permanent magnets are often fixed in the path of flow of the grain to the initial or upper level. The uppermost sieve has oval perforations with dimensions

of $^{9}/_{64}$ to $^{10}/_{64}$ inches. It permits removal of larger stones, straw ends, ears, etc. The middle screen permits passage of barley and smaller seeds, but serves to eliminate some larger grains such as corn. The lower screen usually contains triangular openings so that it retains the barley but sifts out seeds such as flax, mustard, etc.

After the barley leaves the Scalperator or the Eureka-type cleaner, it is directed to machinery designed to separate wheat, oats, seeds and broken barley from the usable barley. An example of a machine used for this purpose is the Carter Disk Separator, which takes advantage of length difference between various materials.

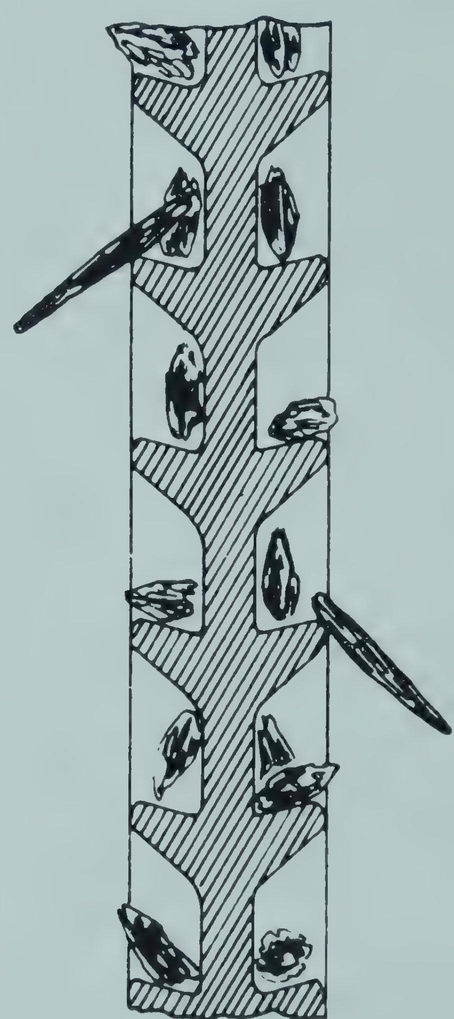


FIG. 121. PRINCIPLE OF SEPARATION BY THE CARTER DISK

Figure 120 is a view of the mechanics of disk separation. While the picture shows a mixture of wheat and weed seeds, the mixture being separated can be construed to be barley and oats. The barley fits into the pockets of rotating vertical disks and is lifted from the mixture while the oats are too long to fit into the pockets and are rejected.

The principle of operation of Carter Disk is depicted in Fig. 121 and shows how materials such as oats are removed.

The Hart Uni-Flow Cylinder Separator is another example of a machine designed to remove wheat, oats, and broken kernels from barley. Fig. 122 illustrates the lifting of material by the Uni-Flow indents (A) and the depositing of it into a conveyor trough (B). The position of the

separating edge (C) of the trough is one factor controlling the fineness or coarseness of the separation to be made. The position of the separating edge can be raised for finer separations or lowered for coarser separations.

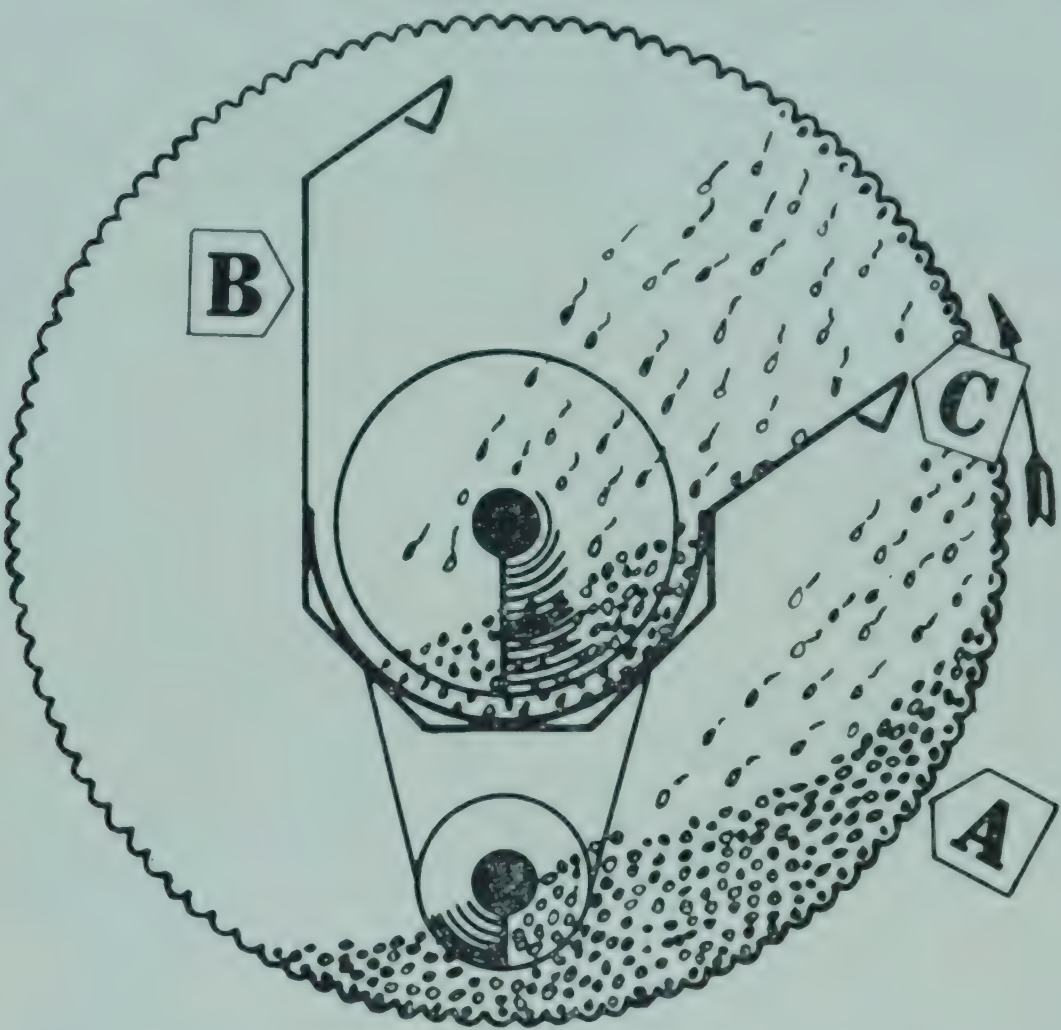


FIG. 122. HART UNI-FLOW CYLINDER SEPARATOR

Material lifted by Uni-Flow cylinder indents (A) is deposited in the conveyor trough (B). The position of the separating edge (C) of the trough is one factor in controlling the fineness or coarseness of the separation to be made. The position of the separating edge can be raised for fine separations; lowered for coarser separations.

After cleaning in the disk or cylinder-type machine, the barley theoretically contains as the only contaminant barley kernels too small for malting.

To effectively separate barley into sizes insuring uniform malt modification, the effluent barley after wheat and oat removal passes into a slotted flat sieve or cylindrical sieve. Most modern processing plants employ Eureka Ring graders or Hart-Carter Precision graders. As an example the Precision grader provides a desirable method of sizing barley by thickness.

One flow sheet of practical operation is the removal of small corn, weed seeds, etc. by treatment on the Eureka cleaner, and passage of the grain via a Scalperator through the Disk or Uni-Flow machine. The effluent is processed in a Eureka or Precision grader, where the initial slot width

may be $7^1/_2/64$ inches. Barley retained by this screen, if Midwestern in origin, may be discarded as incompatible to malting size. Removal of additional corn and soy beans is also thus effected.

The plump or *A* grade malting barley is retained on the $6^1/_4/64$ inch cylinder slot width. Grain passing through a $6^1/_4/64$ inch slot is graded in a cylinder having $5^1/_4/64$ inch or $5^1/_2/64$ inch slots. The retained product is the smaller size adaptable to malting and is catalogued as "B" grade.

STEEPING

The primary purpose of steeping is to introduce water into the barley kernels at a rate and in a manner to permit germination and to produce a well modified and plump malt.

Classical texts indicate that the temperature of the steep water may be raised to a maximum of 68°F. to permit a reduction of the steeping time. However, some doubt does exist as to the quality of malts steeped at the higher temperature levels. It is generally true that the degree of water uptake by the barley kernel, as measured in the laboratory, within certain limits varies directly with the temperature of the water. Nevertheless, judgments as to the completeness of steeping which are based solely on laboratory determined moistures may result in the transfer of insufficiently steeped barley to the germinating areas.

A warm steep is associated with a rapid water uptake which may not permit proper distribution of moisture within the kernel. Leberle (1956) studied water absorption during steeping. The data appearing in Table 91 indicate the tendency of moisture to distribute unequally within the kernel.

Table 91

AREA DISTRIBUTION OF MOISTURE IN STEEPING BARLEY[1]

Kernel Area	Moisture Per cent
Base	47.1
Middle	38.3
Tip	39.1

[1] Leberle (1956).

There is a belief that use of a colder water necessitating a longer exposure to soaking will result in a more uniformly steeped kernel.

Barley is considered to be sufficiently steeped if the moisture content has risen to 42 to 44 per cent. In practical operations, the steep ripeness of the kernel is detected by pinching the two ends between the thumb

and forefinger. If the proper absorption has been achieved, the kernel should open readily and, when it is cut, the moisture should have penetrated to the center.

Physiologically, it is thought that sufficient steeping has been achieved when the cell expansion, due to water uptake, has reached its limit. Then the hydrostatic pressure is equivalent to the osmotic pressure of the cell sap and the condition of cell rigidity is spoken of as the "turgidity" of the cell.

Insufficient steeping adversely affects many aspects of malt quality. Primarily affected are wort clarity and the coarse-fine grind difference of the finished malt. The practical maltster frequently observes greater resistance to the "bite," finding it more difficult to chew the malt.

When differences in steeped-out moisture are relatively small, variations in laboratory-measured quality may not be significant. However, noticeable differences in the plumping tendencies of some malts are observed as a result of varied water absorption during steeping. Table 92 lists the results obtained when an "A" grade Kindred from the 1957

TABLE 92

THE EFFECT OF STEEPING TIME AND MOISTURE ABSORPTION ON THE PLUMPING OF MALT
"A" size Kindred, 1957 crop; Water at 60 °F.

Sieve	Barley Before Steeping Per cent	Steeped[1] 22 hrs. Per cent	Steeped[2] 28 hrs. Per cent	Steeped[3] 40 hrs. Per cent
On $^7/_{64}$ inch screen	1.8	38.2	43.4	49.5
On $^6/_{64}$	71.6	54.5	52.2	48.3
On $^5/_{64}$ inch screen	26.0	6.7	4.1	2.0
Through $^5/_{64}$ inch screen	0.6	0.6	0.3	0.2

[1] Barley contained 38 to 39 per cent moisture.
[2] Barley contained 41 to 42 per cent moisture.
[3] Barley contained 43 to 44 per cent moisture.

crop was steeped at 60° F. with appropriate water changes and then transferred as a water slurry ("wet steep") to the compartment at the indicated moisture levels. Prior to sampling of the steeped barley surface moisture was removed by "venting" with warmer air (68° F. and 80 per cent relative humidity) and germination and kilning were conducted comparably in a conventional and accepted manner.

It should again be noted that, with reference to the water absorption–kernel size data, all other facets of the process were held constant. In drying, the green malt temperature did not exceed 130° F. until the malt moisture decreased to twelve per cent. The barley was vigorous and germinated 98 to 100 per cent.

That barley plumpness is a marked determinant in the steeping time

required is shown by Leberle (1952), who included this factor in his study. The data are presented in Table 93.

TABLE 93

THE RELATION OF KERNEL SIZE TO WATER UPTAKE[1]
Original barley moisture, 13.3 per cent

Steep Time, Hrs.	Kernel size: 2.2–2.5 mm. ($5^1/_2/64$–$6^1/_4/64$)	2.5–2.8 mm. ($6^1/_4/64$–$7/64$)	Over 2.8 mm. (Over 7/64)
	Moisture Content, Per cent		
16	30.9	29.7	29.3
39	37.1	35.8	35.2
62	40.8	39.6	38.9
87	43.1	41.7	41.0

[1] Leberle (1952).

When a "wet" steep-out is employed, understeeping may be partially corrected after transfer to the compartment or drum. Absorption of water has been found to continue up to an additional 2 to 3 per cent where such a procedure is operative. It is advisable that surface evaporation be held at a minimum during the 8 to 15 hour period following discharge from the steep tank. Water can also be given during this period to facilitate after-steeping.

Attempts to increase the moisture content to any marked degree (over 1 or 2 per cent) after the "chit" or onset of acrospire (plumule) growth has begun, create a serious threat of "overgrown" development (condition of the acrospire or prime bud extending beyond the length of the kernel). This condition is undesirable.

Oversteeping markedly delays the onset of germination, encouraging increased mold and bacterial growth. Undesirable odors are often associated with barley steeped in this manner.

The term "oversteep" connotes excessive water absorption. However, laboratory data indicate that it is related to the appearance of the steeped barley and to its subsequent onset of germination. Such conditions are usually associated with extended periods of submersion.

To illustrate, graded mature barley of vigorous germinating capacity was steeped into a 0.03 to 0.04 per cent solution of lime water at 65°F. and pH 9.2. After three hours, during which the grain was agitated every 15 minutes, the pH had fallen to 7.2. After draining, the barley was washed with several changes of water at 65°F.

Steeping at 65°F. was continued in the manner indicated: (A permitted to rest with occasional agitation; (B) steeped under continuous aeration; and (C) steeped with continuous fresh water overflow at 65°F.

TABLE 94

EFFECT OF STEEPING PROCEDURES ON THE CONDITION OF STEEP-OUT BARLEY

Sample	Duration of Steep								
	26 Hours			32 Hours			44 Hours		
Identification	Moisture Per cent	Physical Condition	Chit Per cent	Moisture Per cent	Physical Condition	Chit Per cent	Moisture Per cent	Physical Condition	Chit Per cent
A	42.1	Soft	5–10	42.9	Soft	5–10	45.5	Soft	
B	42.8	Firm	20–25	43.4	Beginning to soften	25–30	46.0	Soft	
C	42.6	Firm	85	43.6	Firm	90	..	Firm	95

The water was drained after 9, 20, and 30 hours (after the beginning of steeping), the barley washed with fresh water and steeping continued as outlined in (A) through (C).

Moisture was determined at 26, 32, and 40 hours, after steeping-in, the physical conditions of the barley being noted. The data are presented in Table 94.

As noted in Table 94, only the barley associated with water changes (A) exhibited oversteeped characteristics after 26 hours. Where continuous overflow was employed (C), the barley reflected a desirable degree of steep after 32 hours and produced an excellent finished malt. Even after 44 hours, this barley appeared to be in good condition and produced a good malt. Aeration (B), while compensating in part for the deficiencies in water change, resulted in a product which, after 32 hours, seemed to be oversteeped.

Yet, it is to be noted that the moisture content of the steeped barley resulting from the three procedures is reasonably comparable.

After germination of the "oversteeped" barley has begun, a retardation of rootlet growth is observed. This is often accompanied by a too rapid elongation of the acrospire. The husk of the malt becomes darkened in color.

It is believed that the effects of so-called oversteeping are the results of the competition by molds and bacteria for oxygen together with a saturation of the steep water with respiratory carbon dioxide. In the experiment just described, the unaerated steep (A) had a pH of 5.4 after 26 hours while its aerated counterpart (B) was at pH 7.2. It may be theorized that there occurs a cessation of oxygen uptake by the cell with the substitution of an anaerobic metabolism. Some of the lingering intermediate or end products of these anaerobic processes are toxic and must be dispelled prior to the onset of germination.

Barley variety also affects the selection of length of steeping time. Data showing the relative water uptake by Montcalm and Kindred (1957 crop year) of comparable kernel size appear in Table 95. The barley was graded to pass through a 6/64 inch screen and to maintain above a $5^1/_2/64$ inch screen.

Kernels of lowered germination energy are said by Leberle (1952) to absorb, under comparable conditions of steep, 0.7 to 2.0 per cent more water than their vigorous counterparts. It is a recognized principle in commercial malting that a reduction in steeping time must be made for barley containing kernels of lowered germinating energy.

It is necessary to supply air to the steeping barley. There are several reasons for this aeration. Aeration protects the barley against the danger of oversteeping. Leberle (1952) postulates that the greater the uptake of

water within the barley during steeping and the less maturation (after harvest) the greater the necessity for the application of oxygen through aeration. Leberle has also found that the evils of oversteeping are not always the result of continued submersion, but rather are due to the contact of the respiring barley with acidic material. Removal of the accumulated carbon dioxide by aeration helps remedy this situation.

TABLE 95

WATER UPTAKE OF KINDRED AND MONTCALM AFTER STEEPING FOR 26 HOURS AT 54°F.

Barley Variety	Moisture Per cent
Kindred	37.8
Montcalm	40.4

Aeration also acts as a means of agitation. The latter is desirable as an aid in washing or scrubbing the grain as well as a precaution against the channeling of the overflow water, which is admitted at the bottom of the tank and flows off the surface of the steeping barley.

DeClerck (1952) recommends that aeration by compressed air be carried out 4 or 5 times a day for 15 to 20 minutes at a time. A volume of 0.23 cu. ft. per 48 lb. bushel delivered at a pressure of 7 lbs. per sq. in. is indicated as desirable. Some investigators feel that a limitation should be placed on the duration and frequency of aeration, believing that excessive oxygen encourages mold growth. However, treatment of the grain with permitted antiseptics in the steep tank can control or alleviate the danger of mold contamination.

Water composition, as directly related to the biological process occurring within the steeping kernel, is not of too great importance because of the semi-permeable membrane which limits access of the water constituents to the cell interior.

Addition of sodium hydroxide or, more frequently, lime, to about pH 9.0 to 9.5 is generally made to the first steeping-in water to assist in the removal of undesirable husk substance.

Warrick *et al.* (1935) studied steep water wastes and observed that approximately 0.28 pounds of dissolved solids were removed per bushel; that usage of 75 gallons of water per bushel occasioned a loss of 0.6 per cent the weight of barley processed. He analyzed the waste produced by each step of the malting process. Table 96 indicates the degree of waste produced in a malting plant.

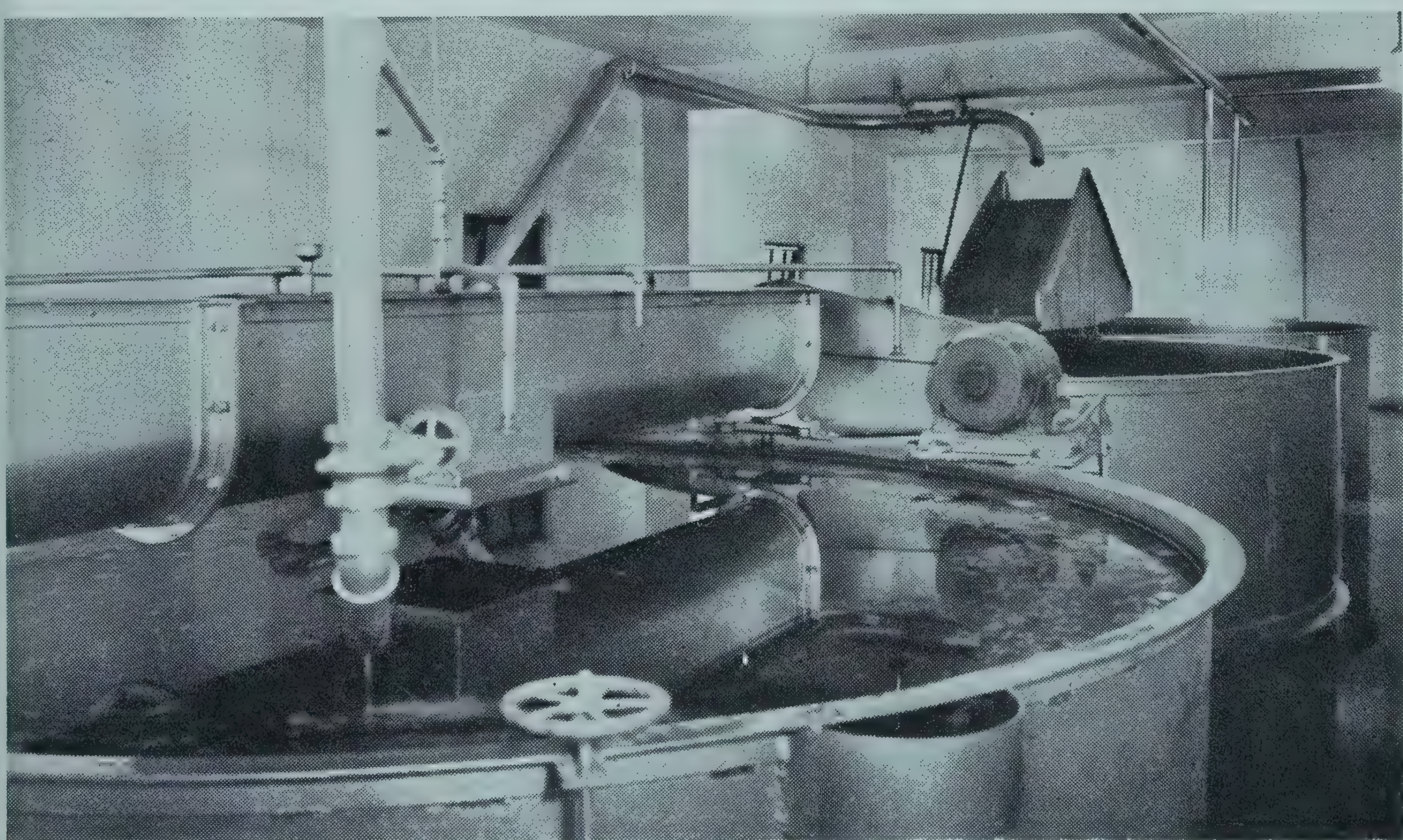
Additional physical concepts of steeping are worthy of note. When observed in a dry state, 500 grams of "B" size Kindred barley have been found to occupy 775 ml. (equivalent to approximately 1.19 cubic feet per

bushel). This agrees with the figure quoted by DeClerck (1952). However, the same quantity of barley, if allowed to drop into a predetermined volume of water, a practice necessary to achieve proper "liming" and to effect the desired removal of "skimmings," will occupy, after settling, about a ten per cent greater volume.

TABLE 96

STEEP WATER WASTE FROM THE MALTING PROCESS

	5 Day BOD	Total Organic Nitrogen	Total Solids	Hours of Contact
1st Steep water	960	69	4856	24
2nd Steep water	920	72	2372	12
3rd Steep water	185	4	418	12
4th Steep water	254	7	452	16
Germ drum water	50	12	534	. .



Courtesy of Stockland Malting Machinery Co.

FIG. 123. STEEP TANK

After steeping, an approximate 30 per cent increase in barley volume is observed (about 1.55 cubic feet per bushel). DeClerk states that, to to insure sufficient coverage of the steeping grain with water, the total mass should be equivalent to about 1.76 cubic feet per 48-lb. bushel of barley steeped.

Fig. 123 portrays a steep tank used in commercial malting. Figure 124 depicts the bottom of a tank. The "screw" valve on the left controls the

Courtesy of Stockland Malting Machinery Co.

FIG. 124. BOTTOM OF A STEEP TANK SHOWING BARLEY OUTLET VALVE

Courtesy of Stockland Malting Machinery Co.

FIG. 125. GERMINATING CHAMBER

Courtesy of Stockland Malting Machinery Co.

Fig. 126. Filling the Germinating Chamber with Steeped Barley

discharge of "dry" steeped-out barley. The pipe to the right of the cone illustrates the mode of draining off water or admitting fresh water.

GERMINATION

Germination is the physiological process in which the lamella or acrospire and the rootlet of the seed are elaborated thus forming a new plant through the multiplication and enlargement of cells. In the malting process, the conditions of germination which are subject to control are moisture, air, temperature and, to a much lesser extent, the carbon dioxide concentration of the air associated with the germinating grain. In the American system, the steeped barley is transferred to the germinating chambers by pumps as water slurry or by screw conveyors in a partially surface-dry state. The bed of grain in the germinating chamber is called a piece.

Germinating chambers are either permanently fixed compartments or cylindrical drums which can be rotated. The compartment type is a rectangular chamber consisting of two parallel longer walls and two shorter ends. It has a depth of 4.5 to 5 feet. The longer walls are 7 to 8 inches thick and are generally constructed of reinforced concrete which has been troweled to a very smooth surface on the inner side. Mounted on the surface of each of the longer walls are a track and a cog rail which support and assist in controlling the passage of the machine which turns or mixes the malt.

The floor is fitted with perforated trays, permitting passage of air through the bed of germinating grain. The area below the compartment varies in depth from 2 to 7 feet, the figure in a particular case being influenced by the available space and by design requirements for an efficient exhaust of air. The perforated bottoms are usually permanently affixed where depths of 5 to 7 feet exist, since washing with high-pressure water can be accomplished without raising the trays. More shallow sub-compartments require lifting the trays to permit washing.

Aeration of the malting compartment is either updraft or downdraft. It has been reported that some installations permit a combination of the two systems.

Most American installations expose the surface of the germinating grain within the compartments to the atmosphere of a large room. When this arrangement is employed, the updraft system provides the maltster with the greatest degree of control. Each compartment may be appointed with individual heating coils or with gas jets which warm the air directly. Where refrigerated, the water temperature of the individual humidifiers may be controlled. New designs permit selection of desired air velocity by assignment of a single fan to 1 or 2 compartments.

The attempered humidified air is forced through the green malt and is permitted to pass through ducts to the outside. More often, the duct work and air valves are so arranged as to permit recirculation of part or all of the compartment exhaust air. Such an arrangement is generally the case where the water of the humidifiers is refrigerated.

In the downdraft system all compartments are exposed to the impact of the same humidified and attempered air. The only controlled variable specific to the individual compartment is the velocity of the air passing through the piece. The compartment room is generally adjusted to 54° to 56° F., the moisture content of the air being saturated or near saturation.

The heat of respiration of the germinating grain is utilized in the adjustment or control of the temperature of the piece. While the exhaust system applies a negative pressure common to all compartments, the degree of opening of the draft door in the sub-compartment area controls the velocity of air passage through the piece. Air passage, in turn, is regulated to permit the desired temperature build up to occur.

Within compartment installations, be it an updraft or downdraft system, smaller amounts of air, approximately 2 to 3 cu. ft./bu./min., are demanded during the first three days of germination. Less resistance is exerted against the passage of air due to the presence of shorter rootlets. Moreover, the germinating grain has as yet not reached the peak of respiration.

After watering and succession to the fourth day of growth, temperature control demands a larger quantity of air, approaching a minimum velocity of 5 to 6 cu. ft./bu./min.

The term "*continuous*" *ventilation* implies a procedure demanding air passage through the bed of malt from the time of loading to the time of withdrawal for kilning. The referred to process of venting, applied to remove excess surface moisture resulting from a wet steep-out, may be included to initiate the malting period of continuous aeration. An outline of one method will be presented. The steeped barley enters the compartment at 60°F. If, in the instance of a "wet" steeping-out procedure, a colder steep water (50°F.) has been employed, the barley may be transferred in slurry with water which has been warmed to 65° to 68°F.

The bed of germinating grain is either vented with warmer air or the normal humidified air at 54° to 56°F. is passed through at the rate of 1 to 2 cu. ft./bu./min. immediately after leveling of the steeped-in barley. After 30 hours, during which the stirring machine has effected 2 to 3 passages, a light watering is applied and the air velocity is increased to 2 to 3 cu. ft./bu./min. It is estimated that the quantity of this "pre-water" is slightly in excess of a quarter of a gallon per bushel.

After about 55 hours, a second watering, in extent of 1 to $1^1/_4$ gallon per bushel is applied and the air velocity is increased to about 7 to 8 cu. ft./bu./min. After a warming to about 62°F. immediately after watering the piece cools down to about 56°F. and this temperature is retained for the remainder of the germinating period.

Larger kerneled barley frequently requires a light third watering. However, such practice is frequently responsible for excessive moisture retention within the green malt at the time of transfer to the kiln.

Malts prepared in a system of continuous aeration are characterized by a lower soluble protein content and by paler colors after boiling. When properly kilned, they exhibit a malty flavor.

In discussions of the method of **interrupted ventilation,** the term "couching" is frequently found. In earlier texts, the practice of "couching" meant permitting conical heaps of steeped-out barley to rest undisturbed for periods up to 24 hours. The heaped barley would become warm, thus assisting the onset of germination. "Couching" in this manner is not recommended as it promotes a lack of uniformity resulting from the temperature gradient existing from center to surface of the heap.

Today, "couching" means the procedures of leveling a compartment after steeping-in and permitting the temperature within the piece to rise to 64° to 66° F. by arresting the air passage. Air is then circulated at the rate of 2 to 3 cu. ft./bu./min. to maintain a temperature of 60° to

62° F. The draft door of the compartment may be closed during the passage of the turning machine.

After 24 to 36 hours of "couching," aeration is increased to create a temperature of 58° to 60° F. When the rootlet approaches 0.5 cm. in length, water is applied at the rate of one-and-one-quarter gallons per bushel. Ventilation is conducted at the rate of 7 to 8 cu. ft./bu./min. during and after watering. When the surface moisture has disappeared, accompanied by a concurrent drop in temperature to about 54° F., the draft door is closed and the piece permitted to warm to 66° to 68° F.

Cooling as rapidly as possible to 54° F. is then effected and the draft door closed to again achieve the upper temperature limit. Each cycle of warming and cooling usually requires 6 to 8 hours.

Continuous aeration at the rate of 6 to 7 cu. ft./bu./min. is conducted during the last 12 to 15 hours.

Malt prepared by the "interrupted" process, when contrasted with that produced with "continuous" ventilation, exhibits some of these characteristics:

(1) Darker wort color and darker color after wort boiling; (2) higher alpha-amylase activity and increased soluble protein; (3) increased extract with smaller coarse-fine grind difference; and (4) greater mealiness when crushed and chewed.

It has been stated that the temperature of the ventilating air is a prime factor affecting malt quality.

Hind (1938) presented data for extract and soluble protein composition of malts germinated at three temperature levels within the range of 55° to 72° F. It is assumed that the temperatures have been applied in a manner of continuous ventilation. While the germinating time consisted of nine days, analytical values for a period thought to coincide with a peak in modification are recorded in Table 97.

TABLE 97

EFFECT OF GERMINATING TEMPERATURE ON MALT CHARACTERISTICS[1]

	Temp. Range, ° F.	Days Growth		
		5	6	7
Soluble protein as per cent total nitrogen	55.4–62.6	38.3	36.8	37.6
	59.0–68.0	35.5	34.2	31.9
	66.2–71.6	32.1	31.2	30.0
Extract, per cent (dry)	55.4–62.6	79.2	79.4	79.7
	59.0–68.0	78.6	78.2	78.3
	66.2–71.6	78.5	78.2	78.2
Acid (ml. 0.10 N NaOH to pH 9.2 for 100 ml. wort)	55.4–62.6	16.1	15.3	15.6
	59.0–68.0	14.6	14.1	14.0
	66.2–71.6	14.1	14.1	14.0

[1] Hind (1938).

The previously cited flow sheets of germination employing continuous or interrupted ventilation denote the use of several temperature levels.

Dickson and Shands (1942) studied the effect on quality when germinating four barley varieties for six days, using a constant moisture level of 45 per cent and temperatures of 53.6°, 60.8°, and 68°F. singly and in varied sequence. Generally speaking, a two-day period of 60.8°F. followed by four days at 53.6°F. produced malts with the greatest recovery and with quality factors which coincide with present-day brewery specifications.

Germination at one fixed moisture level will result in a malt differing in quality from that produced at another level.

Klopper and Kortenhorst are quoted by Kolbach (1955) as steeping barley at 54.5°F. for 45 hours and recording a steep-out moisture of 40.2 per cent. Germination was conducted at this level and at additional levels of increased moisture content which were achieved by watering on the first and second days of germination. The control of rootlet growth, diastatic power and soluble protein is noted in Table 98.

TABLE 98

THE EFFECT OF MOISTURE LEVEL WITHIN GERMINATING BARLEY ON THE QUALITY OF THE RESULTANT MALT[1]

	Green Malt Moisture Level Per cent			
	40.2	42.6	43.9	48.2
Rootlets as per cent dry barley	2.1	3.0	3.4	4.6
Diastatic power[2]	160	180	195	205
Soluble protein as per cent of total protein	39	41	42	44

[1] Klopper and Kortenhorst as quoted by Kolbach (1955).
[2] Degrees Lintner.

The proper duration of the germinating period is a subject which has reflected a difference of opinion among commercial maltsters. It has been reported that 4-, 5-, and 6-day germinating malts are being prepared from midwestern-type barleys.

First, it may be well to distinguish between the propriety of one processor germinating for five days while another utilizes six. In the five-day process, a "dry" steeping-out, where the onset of germination may have begun in the steep tank, could have been employed. In the instance of six-day malt, the barley may have been discharged into the germinating chamber as soon as the proper steep-out moisture was achieved. Reasonably comparable germinating periods may have existed in both procedures.

To achieve satisfactory modification, plumper kerneled midwestern and two-row barleys often require longer periods of germination. Thus, the length of germinating time may be varied within one process.

DeClerck (1952) and others present curvilinear data for respiration, diastatic and proteolytic activity, depicting a peak between the fourth and fifth day of germination. When, in practical operations, germination has been arrested at this period, malts are obtained which yield satisfactory analyses in most areas of quality. However, studies have been conducted which suggest that the arresting of germination at the indicated peak may result in malts lacking in one or more essential qualities.

Meredith and Bendelow (1956) examined additional properties of worts and showed that viscosity was a useful measure of quality factors associated with modification that were not measured in other determinations. He found that the viscosity of Congress wort was a direct reflection of the modification process and of the ease of conversion of some carbohydrate material in the barley into solubles in the wort. He also presented evidence of a close relation between the viscosity of the 158° F. worts and the amount of cold-water extract. Low values for cold-water extract are associated with high wort viscosity.

Table 99 shows the increase of cold-water extract of the variety Montcalm when malted 5 and 6 days at moisture levels of 42.0 and 44.0 per cent.

TABLE 99

GERMINATING TIME AND MOISTURE LEVEL AS FACTORS IN COLD WATER EXTRACT DEVELOPMENT[1]

Moisture, Per cent	Cold Water Extract, Per cent	
	5-Day Germination	6-Day Germination
42	16.8	19.2
44	18.0	20.4

[1] Meredith and Bendelow (1956).

For purposes of references, Meredith has shown the relationship of cold-water extract and the viscosity of 158° F. malt worts prepared from different barley varieties. Values are presented in Table 100.

TABLE 100

COLD WATER EXTRACTS AND WORT VISCOSITIES FROM DIFFERENT VARIETAL MALTS[1]

Malt Sample Identification	Cold Water Extract Per cent	Viscosity[2]
A	14.0	2.24
E	16.7	1.85
F	18.1	1.70
L	20.0	1.54

[1] Meredith and Bendelow (1956).
[2] Centipoise.

Another factor which is claimed to effect malt quality is the carbon dioxide content of the air surrounding the grain. Hind (1938) cites the study of Hoffman-Bang who found that the greatest percentage of salt-soluble nitrogen could be obtained from malts made at the lowest temperatures and in the presence of carbon dioxide.

Leberle (1952) presents data observed in the interrupted or intermittent aeration of a pneumatic compartment. After the piece had achieved maximum respiration, a four-hour cessation of ventilation was accompanied by a marked increase of the carbon dioxide content of the air. The data appear in Table 101.

TABLE 101

BUILD-UP OF CARBON DIOXIDE DURING INTERMITTENT VENTILATION[1]

Age of Piece Days	Length of Rest Hours	CO_2 Content of Air	
		Lower Half Per cent	Upper Half Per cent
2	2	6.0	5.4
2	4	9.6	7.0
3	2	7.0	6.0
5	2	7.5	6.0
6	4	15.6	10.4
7	2	8.7	6.0

[1] Leberle (1952).

Lack of data comparing carbon dioxide build-up during continuous ventilation with that resulting from interrupted ventilation prevents a contrast of quality. Values do exist which contrast malt from the Kropf carbon dioxide system with malt from the pneumatic compartment methods. These are presented in Table 102.

TABLE 102

COMPARISON OF THE QUALITY OF GREEN MALT RESULTING FROM A PNEUMATIC COMPARTMENT AND THE KROPF CARBON DIOXIDE SYSTEM

	Pneumatic	Kropf
Moisture, per cent	42.0	43.5
Total acids, ml. N/1	12.7	13.3
Total formol N, mg./100 gm. malt	315	380
Diastase, degrees Lintner	340	380
Invert sugar, per cent	2.76	3.00
Sucrose, per cent	5.40	4.72

A brief description of the pneumatic compartment has already been presented. As indicated, the alternate method for conducting germination is within a drum. Rotation of the drum serves as a means of agitation or mixing the green malt. Tempered and humidified air flows to

the drum as the result of the negative pressure imposed by withdrawal of the exhaust air. Germinating temperatures within the drum are estimated by the temperature of the exhaust air. DeClerck (1952) provides a more complete description of the Galland drum and its operation.

Several recent installations provide for drying and kilning the malt directly in the compartment in which the germination took place. However, most installations require removal of the malt from the compartments and conveyance to a kiln. For purposes of labor saving, green-malt removal machines have been installed. Generally, one man is thus able to transfer malt from the compartment. An example of such a machine is portrayed in Fig. 127.

Fig. 127. Removing Green Malt from the Germinating Chamber

KILNING

Efficient kilning consists of drying the green malt at a maximum rate of water removal within a temperature gradient which permits retention of desired quality factors and which causes other factors of quality to be created.

There are 2 and possibly 3 distinct phases which must be considered in kilning. The operation commences when the moisture level of the green malt is approximately 45 per cent. In this initial stage, enzymatic degradation and breakdown still go forward because the gradual drying

accomplished at lower temperatures permits sufficient moisture to be retained in part of the green malt bed. The second phase of kilning, accomplished by heating after the moisture level of the malt has decreased below 10 per cent, may be considered the final drying or curing, during which chemical or physico-chemical reactions take place within the constituents of the malt.

When "sulfuring" is practiced, the application of sulfur dioxide may be considered a distinct phase of kilning. "Sulfuring" is generally conducted while the moisture level of the green malt exceeds 40 per cent.

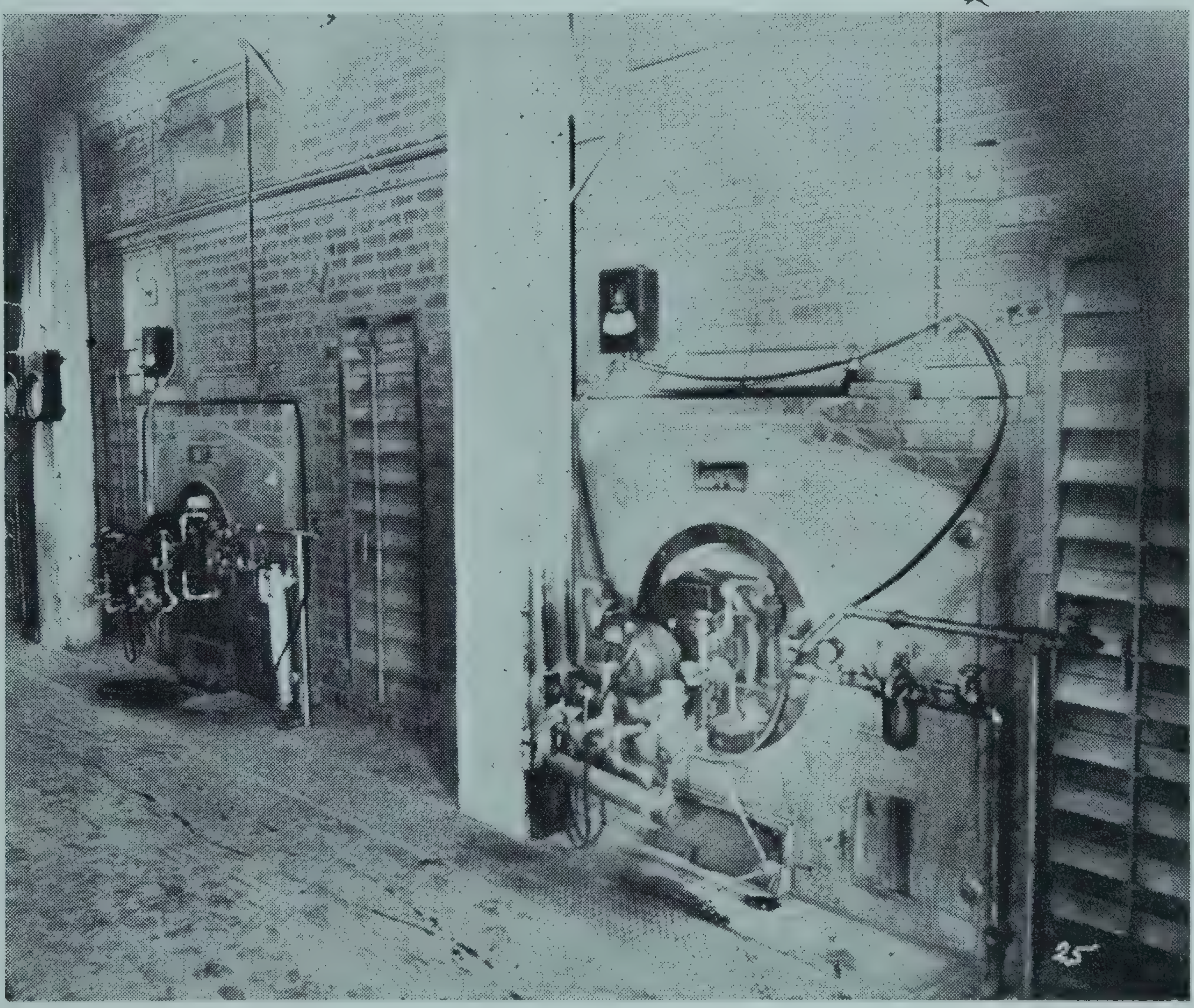


FIG. 128. KILN FIRING INSTALLATION

Most of the malt currently manufactured is dried by direct exposure to the heat of furnaces using natural gas or mixtures of propane and butane. A few installations still employ fuel oil. However, the use of oil other than for stand-by purposes is to be discouraged because of a possible danger of soot or film deposit on the malt. The combustion of sulfur-containing oils also result in an uncontrolled contact of the product with sulfur dioxide.

Kilns consisting of 1, 2, or 3 levels are generally employed. When the sequence of drying in two or more levels is considered, it is implied that the heated air first passes through the lower bed of malt, which by nature

of position and length of exposure, is the driest. Air leaving the lower level is drawn up through the second or middle bed, which is of an intermediate degree of dryness, and finally through the third or upper bed which has accommodated the last or most recent loading of green malt. A fan, or series of fans, situated above the upper level thus exhausts air whose initial drying characteristics are established in the heating chambers below the first level. Exceptions to the outlined manner of heat application as effects the drying properties of the air will be presented later in the discussion.

The depth to which a kiln may be loaded is dependent on the draught which is to be passed through the bed of green malt. Generally, an air velocity of 60 to 70 cu. ft./bu./min. is considered adequate to remove moisture to a sufficiently low level to permit application of the hot air for the duration of the curing period, thus allowing sufficient time for the operation to coincide with the production schedule. DeClerck (1952) presents values for the volumes occupied by malt at degressive stages of moisture during kilning. The data, appearing in Table 103, are calculated on a malt bushel dry basis. The figure showing one bushel (dry basis) at 45 per cent moisture as occupying 2.18 cubic feet coincides well with the value of one cubic foot of green malt weighing about 22 lbs.

TABLE 103

EFFECT OF MOISTURE DECREASE DURING KILNING ON THE VOLUME OCCUPIED BY MALT[1]

Moisture Content of Malt Per cent	Volume, Occupied by One Malt Bushel, Dry Basis Cu. Ft.
45.0	2.18
40.0	2.02
30.0	1.69
20.0	1.36
10.0	1.09
5.0	0.98

[1] DeClerck (1952).

The malt moisture to air temperature relationship is extremely important during kilning from the standpoint of malt quality. This relationship is accentuated at the higher moisture levels. Hind (1938) presents data published by Kolbach and Schild in Table 104 which indicates the temperature effect on the increase in soluble nitrogenous compounds.

Practical experience has shown that wort color and flavor parallel, though to a lesser degree, the increase of soluble nitrogen achieved in this manner. Witt (1945) has noted that an increase in diastatic power is also observed.

A recent study by Grünewald (1954) compares two malts resulting from drying schedules in which the heat was raised to 140°F. after 6 and 10 hours, respectively, following kiln loading. The same air velocities were employed initially. However, increases in temperature were accompanied by decreases in air velocity. The time-temperature diagram and the data reflecting the effect on nitrogen solubility appear in Fig. 129 and Table 105, respectively.

TABLE 104

INFLUENCE OF TEMPERATURE AND MOISTURE ON THE "SOLUBLE PROTEIN" FORMATION DURING KILNING[1]

Moisture (Green Malt) Per cent	Lowest Temp. of Increase Occurrence °F.	Maximum Temp. of Increase Occurrence °F.	Maximum Increase Protein[2]
43	72	133–136	18.7
34	79	Above 140	14.3
24	104	144–151	9.3
15	122	151–158	3.7

[1] Kolbach and Schild, as quoted by Hind (1938).
[2] Soluble protein tabulated as the per cent soluble of total protein, assuming a 10 per cent total malt protein.

TABLE 105

THE FUEL AND LENGTH OF TIME REQUIRED FOR TWO KILNING SCHEDULES STUDIED AND EFFECTS OF THE TWO METHODS ON PROTEIN BREAKDOWN[1]

	Schedule 1	Schedule 2
Heat requirements (B.t.u. per malt bu.)	98,000	75,000
Time requirement (hrs. on the kiln)	21.5	18.7
Soluble protein increase (per cent soluble/total)	41.5	44.2

[1] Grünewald (1954).

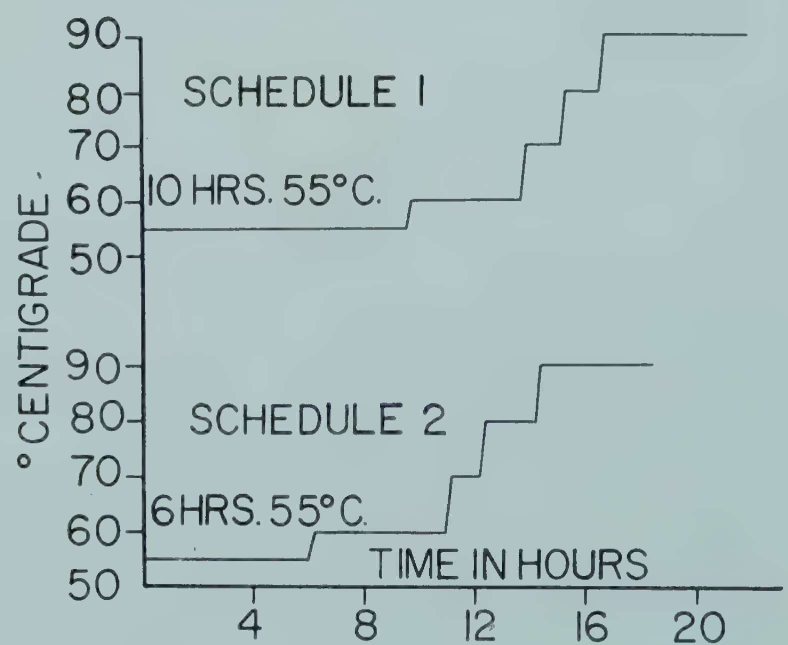


FIG. 129. DRYING SCHEDULE OF TWO MALTS

Temperature was raised to 140°F. after 6 and 10 hours, respectively, following kiln loading.

It is to be noted that the lower temperature drying schedule required about 30 per cent more heat and necessitated two hours and 45 minutes additional kilning time. The investigator indicates that an initial low temperature kilning period was associated with a paler wort color and

with a smaller fine-coarse grind extract difference which had only been previously achieved by germinating an additional day.

However, modern kiln design and economical operating procedures may be used to achieve low temperature kilning at higher moisture levels without the sacrifice of air velocity or the expenditure of additional fuel.

A by-pass system may be installed in a two level kiln which may be regulated to provide for an admixture of non-heated air with that passing through the malt bed on the lower kiln. In this manner, higher temperatures may be employed on the lower kiln without adversely affecting the newer malt on the upper kiln.

Examples of kilning methods comparing the use of by-pass outside air with a system where all the air employed originates in the heating chambers appears in Table 106.

Table 106

HEAT REQUIREMENT FOR DOUBLE KILN EMPLOYING DIRECT HEAT CONTRASTED WITH ONE USING BY-PASS AIR

	Direct Heat		
	Entrance Air Heat Chamber	Exit Air Heat Chamber	Exit Air Malt Bed
Temperature, °F.	32	135	73
Relative humidity, per cent	80	2.3	90
Moisture of air (water per 100 lbs. dry air)	0.303	0.303	1.573
Heat content (Total B.t.u. per 100 lbs. dry air)	1096	3528	3528
Water removal (B.t.u. per pound of water)	...	...	1947
Quantity water removed first hour after loading, lbs. (2,000 bu. at rate 60 cu. ft./bu./min.)	...	...	6788

	By-pass Air Employed (20 Per cent Admixture)			
	Entrance Air Heat Chamber	Exit Air Heat Chamber	Entrance Air Upper Kiln	Exit Air Upper Kiln
Temperature, °F.	32	135	93	67
Relative humidity, per cent	80	2.3	24	90
Moisture of air (water per 100 lbs. dry air)	0.303	0.303	0.720	1.278
Heat content (total B.t.u. per 100 lbs. dry air)	1096	3528	3040	3040
Water removal total (B.t.u. per lb. of water)	...	...	...	1870
Total quantity water removed first hour after loading, lbs. upper and lower kiln	...	...	...	5492

It is to be noted that, in the instance of the by-pass, the air entering the bed of green malt is 93° F. as contrasted with 135° F. where no direct outside air is used. In computing the data associated with the by-pass

air, it is assumed that the malt in the lower kiln has a moisture content of about ten per cent and that the relative humidity of the air leaving that malt is 16 per cent. It is also assumed that the 20 per cent admixture of outside air reduces the velocity and quantity of air passing through the heating chamber and the lower kiln while permitting passage of the maximum quantity through the upper kiln. A detailed example of the calculation appears on p. 505.

Table 107

HEAT REQUIREMENT FOR DRYING SINGLE LEVEL KILN—DRYING EFFICIENCY OF GERMINATING COMPARTMENT EXHAUST AIR CONTRASTED WITH THE CONVENTIONAL USE OF OUTSIDE AIR

	All Outside Air		
	Entrance Air Heat Chamber	Exit Air Heat Chamber	Exit Air Malt Bed
Temperature, °F.	32	122	70
Relative humidity, per cent	80	3.5	90
Moisture of air (lbs. of water per 100 lbs. dry air)	0.303	0.303	1.420
Water removal (B.t.u. per pound of water)	...	...	1920
Quantity water removed: lbs. in first hour after loading (2,000 bu. at rate 60 cu. ft./bu./min.)	...	...	6098

	70 Per cent Germinating Compartment Air		
	Entrance Air Heat Chamber	Exit Air Heat Chamber	Exit Air Malt Bed
Temperature, °F.	51	122	75.5
Relative humidity, per cent	96	9	90
Moisture of air (lbs. of water per 100 lbs. dry air)	0.762	0.762	1.718
Water removal (B.t.u. per pound of water)	...	...	1754
Quantity water removed: lbs. in first hour after loading (2,000 bu. at rate 60 cu. ft./bu./min.)	...	...	5347

The economics of fuel consumption are comparable, each system requiring about 1940 B.t.u. to remove a pound of water during the initial drying period. The difference occurs in that 30 per cent less water is removed during the first hour when by-pass air is used. It is not to be construed that the entire kilning period is lengthened to this degree, as this wide difference exists only with the first 2 or 3 hours of drying. Generally, the entire drying period is only lengthened by a few hours.

Obviously, the factor of increased drying time can be compensated for by augmented fan power. It is reasonable to assume that the cited air velocity of 60 cubic feet could be increased to 75 cu. ft./bu./min. to achieve the desired drying in a comparable length of time.

Control of the humidity of the heated air entering the kiln has been

recognized to be of value in achieving malt quality. Pale malts of desirable mellowness and soluble nitrogen have been prepared by drying with an initial air temperature of 120° to 130° F. and a relative humidity of 15 to 20 per cent.

Experimental kilning has been conducted where the humid exhaust air from the germinating chambers has been mixed with outside air prior to entering the heating chambers. A time-temperature diagram of drying employing a mixture of 70 per cent exhaust air and 30 per cent outside air appears in Table 107.

While the example of the use of *all* outside air was shown to affect an approximate twelve per cent greater moisture removal the first hour, admixture of the malt house exhaust air achieved almost 10 per cent less heat expenditure per pound of water removal.

Dickson (1942) has studied some of the changes which occur in malt within the final kilning or curing period. This phase is arbitrarily assumed to begin when the moisture falls below 10 to 12 per cent.

Increased heat is responsible for a marked decrease in diastatic power and a small reduction in extract. The soluble protein remains comparable at the kilning temperature investigated. The data is presented in Table 108.

TABLE 108

THE INFLUENCE OF TEMPERATURE AND TIME OF DRYING ON THE COMPOSITION OF MALTS MADE FROM ODERBRUCKER AND WISCONSIN BARBLESS BARLEYS—1939 SERIES

Drying Treatment[1] Temperature in °F.	Moisture Per cent	Diastatic Power °L.	Extract Dry Basis Per cent	Soluble Protein[2]
Oderbrucker variety				
12 hrs. at 113	6.1	221	72.9	38.9
12 hrs. at 113; 4 hrs. at 131; 4 hrs. at 149	4.5	193	73.0	38.5
12 hrs. at 113; 4 hrs. at 131; 6 hrs. at 149; 2 hrs. at 167	3.7	165	72.6	38.5
12 hrs. at 113; 4 hrs. at 131; 6 hrs. at 149; 2 hrs. at 167; 2 hrs. at 185	3.2	135	72.3	38.5
Wisconsin Barbless variety				
12 hrs. at 113	7.1	119	74.3	32.5
12 hrs. at 113; 4 hrs. at 131; 4 hrs. at 149	4.9	107	74.6	30.5
12 hrs. at 113; 4 hrs. at 131; 6 hrs. at 149; 2 hrs. at 167	3.9	85	73.9	30.5
12 hrs. at 113; 4 hrs. at 131; 6 hrs. at 149; 2 hrs. at 167; 2 hrs. at 185	3.1	60	73.5	30.0

[1] All samples received 8 hrs. drying at 77°F. plus 4 hrs. at 95°F., plus additional treatment indicated.
[2] Soluble protein as per cent of total protein assuming a total malt protein of 12.5 per cent.

Drying at temperatures about 190° F. is frequently associated with a reduction of the soluble protein as a result of the amino acids entering into the reactions responsible for melanoidin formation. When measured

analytically, the alpha-amylase activity is reduced but slightly when malt is kilned off below 180° to 185°F.

The activity of limit-dextrinase and of some of the proteolytic and viscosity reducing enzymes, as well as others presently unclassified, is rapidly diminished at temperatures above 140° to 150°F.

EXAMPLE OF KILN HEATING REQUIREMENT

I. Admixture of Fresh Air with the Heated Air Exhausted from Lower Kiln as Affects the Drying of the Green Malt on the Upper Kiln

Example A (Control).—No admixture of fresh air; all drying air passes through the heating chambers. This may be construed to be a single level kiln and the malt is a newly-loaded lot with a moisture of 45 per cent.

1. Fresh air enters heating chambers at 32°F., 80 per cent relative humidity and contains 0.303 lbs. of water and 1096 B.t.u. per 100 lbs. dry air.
2. The air is heated to 135°F., has a relative humidity of 2.3 per cent and a calorific content of 3568 B.t.u. per 100 lbs. of dry air.
3. The air is exhausted from the upper kiln at 73°F., 90 per cent relative humidity and contains 1.573 lbs. water per 100 lbs. dry air.
4. Calculations
   a. Heat requirements: $\dfrac{3568 - 1096}{1.573 - 0.303} = 1947$ B.t.u./lb. water removed.
   b. Evaporation rate: 2,000 bushels at 45 per cent moisture are ventilated for one hour at the rate of 60 cu. ft./bu./min. under the condition stated.
   Water evaporated first hour:

$$2000 \times 60 \times 60 \; \frac{(1.575)}{(13.75 \times 100)} - \frac{(0.303)}{(15.05 \times 100)} = 6788 \text{ lbs.}$$

Example B.—The lower level of a two stage kiln contains malt at 10 per cent moisture. The upper kiln is newly loaded, the green malt moisture being 45 per cent. A by-pass or opening to the outside air exists between the decks of the lower and upper kiln.

1. The process is started when the malt in the lower kiln has 10 per cent moisture. The air exhausted from the malt has a temperature of 108°F. and 16 per cent relative humidity. Contained in 100 lbs. of dry air are 0.890 lbs. of water and 3527 B.t.u.
2. Admixture of 20 per cent outside air is affected. The air has a temperature of 32°F., 80 per cent relative humidity and contains 0.303 lbs.

of water and 1096 B.t.u. per 100 lbs. dry air.

3. The mixture of air entering the bed of malt on this upper kiln has a temperature of 93° F., 21 per cent relative humidity and contains .0720 lbs. of water and 3040 B.t.u. per 100 lbs. dry air.

4. The air, exhausted from the green malt on the upper kiln, has a temperature of 67° F. and 90 per cent relative humidity and contains 1.278 lbs. of water per 100 lbs. dry air.

5. Calculations

a. Heat requirements:

$$\frac{(0.890 - 0.303)(3527 - 1096 + (1.278 - .720)(.8 \times 3527) - 1096)}{1.278}$$

$$= 1870 \text{ B.t.u.}$$

$$\frac{1870}{1.145} = 1633 \text{ B.t.u./lb. water removed}$$

b. Evaporation rate employed is 60 cu. ft. per bu. per min. Upper and lower kiln each contain 2,000 bushels of malt.

$$0.8 \times 7{,}200{,}000 \; \frac{(0.890)}{(14.48 \times 100)} - \frac{(0.303)}{(14.98 \times 100)} = 2375 \text{ lbs. water}$$

Upper kiln:

$$7{,}200{,}000 \; \frac{(1.278)}{(13.53 \times 100)} - \frac{(0.720)}{(14.07 \times 100)} = 3117 \text{ lbs. water}$$

Total Water Removal First Hour: 2375 + 3117 = 5492 lbs.

II. Admixture of Germinating Compartment Exhaust Air (59° F., 90 per cent relative humidity) with Outside Air (32° F., 80 per cent relative humidity)

Example A (Control).—Air at 32° F., 80 per cent relative humidity heated to 122° F. All drying air passes through the heating chambers. The calculations parallel *Example A, 4 of No. I.*

4. a. Heat requirements:

$$\frac{3214 - 1096}{1.420 - 0.303} = 1920 \text{ B.t.u./lb. water removed}$$

b. Evaporation rate (2,000 bushels at 60 cu. ft. per bu. per min.).

$$7{,}200{,}000 \; \frac{(1.420)}{(13.4 \times 100)} - \frac{(0.303)}{(14.60 \times 100)}$$

$$= 6098 \text{ lbs. evaporated first hour}$$

Example B.—Seventy per cent exhaust air (59°F., 90 per cent relative humidity) mixed with 30 per cent outside air (32°F., 80 per cent relative humidity). All drying air passes through the heating chambers. This example, as well as "Example A," above, may be construed to treat a single level kiln and the malt is a newly-loaded lot with a moisture of 45 per cent.

1. Germinating exhaust air at 59°F. and 90 per cent relative humidity contains 0.9594 lbs. of water and 2439 B.t.u. per 100 lbs. dry air.

Outside air at 32°F. and 80 per cent relative humidity contains 0.3025 lbs. of water and 1096 B.t.u. per 100 lbs. dry air.

2. Seventy per cent germinating exhaust air plus 30 per cent outside air, when entering heating chambers, has a temperature of 51°F. and nine per cent relative humidity and contains 0.762 pounds of water and 2036 B.t.u. per 100 lbs. dry air.

3. When exhausted from the bed of malt, the air has a temperature of 75.5°F. and 90 per cent relative humidity and contains 1.718 lbs. of water per 100 lbs. dry air.

4. Calculations

a. Heat requirements:

$$\frac{3713 - 2036}{1.718 - 0.762} = 1754 \text{ B.t.u. per lb. water removed}$$

b. Evaporation rate (60 cu. ft. per bu. per min.; 2000 bu. of malt).

$$7{,}200{,}000 \frac{(1.718)}{(13.7 \times 100)} - \frac{(0.762)}{(14.9 \times 100)}$$

$$= 5347 \text{ lbs. water evaporated first hour}$$

Sulfur Dioxide in Kilning

A large quantity of the malt finding its way into commercial channels is sulfured. Sulfur dioxide, originating from the burning of lump sulfur or the evaporation of liquefied gas, is applied to the green malt immediately after kiln loading. When burned, pans containing the sulfur are placed adjacent to the heating chambers and the gas is drawn up into the malt as dispersed in the heated air.

When considered quantitatively, the gas from the burning sulfur appears to be more effective than that evaporated from the liquid phase, probably due to the presence of trioxides in the former. Gas from the liquid phase has value as its rate of application can be more readily controlled. One system available for controlled application of sulfur dioxide is that designed by the Virginia Smelting Company.

Among the primary objectives of the application of sulfur dioxide are the bleaching of the malt and the destruction of possible mold and bacteria whose presence during initial drying may be detrimental to quality.

Use of sulfur dioxide is associated with an increase of soluble protein and extract. Witt and Adamic (1957) studied the effect of kiln sulfur dioxide on the malt proteolytic activity exerted during mashing. The degree of sulfuring was considered to be relatively heavy and was equivalent to the passage of 2250 cubic feet of air containing 0.08 per cent sulfur dioxide through one bushel of malt.

It was demonstrated that this degree of sulfuring was responsible for the increase of the acidity of the mash from pH 5.7 to pH 5.3.

The increase in total soluble protein as affected by sulfuring approximated 30 per cent. It was concluded that:

1. Part of the increase was independent of mashing and existed as preformed "proteins," probably enzymatically formed during the initial kilning phase.

2. Depression of the acidity by 0.4 pH units was associated with the acceleration of mash proteolytic activity.

3. Kiln sulfuring was responsible for an actual net increase of enzymatic activity which, in itself, was independent of the effect of mash pH value.

Use of kiln sulfur dioxide is known to produce malts of resultant sulfur dioxide content. However, laboratory beers, when compared with those from unsulfured malts, do not reflect the increases observed in the sulfured malts (Witt 1950).

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Donald W. Ohlmeyer

Brewing

INTRODUCTION

The fermentation of cereal grains to produce beer is as old as history itself, and the basic processes used today are essentially the same as those used in ancient times. The application of scientific methods to brewing has resulted in more detailed knowledge of the reactions taking place and has thus enabled control of the various steps to obtain the type of beer desired and to ensure a product having optimum flavor, color and stability.

A brief general description of the brewing process will be given first, and the details of the various steps will be dealt with in later sections.

The main ingredient in beer is malt. Malt is usually prepared from barley which has been soaked in water, drained, and sprouted until the acrospire (plumule) has grown to an average length equal to three-fourths of the kernel length. The green (moist) malt is then dried to halt growth and stored. Malting develops the amylolytic enzymes which change starch to fermentable sugars, the source of the alcohol in beer. Malt also contains proteins, protein breakdown products and a host of other chemical entities which are a source of flavor and act as nutrients for the yeast during fermentation. An extensive discussion of the malting process is given in Chapter 18.

Corn and rice are used as adjuncts in present-day brewing, to obtain the paler, snappier, less filling beer preferred by today's consumers. These adjuncts are heated to boiling in the presence of a small amount of malt to furnish amylolytic enzymes. The heating gelatinizes the starch, permitting more rapid attack by the enzymes, which liquefy the gelatinized starch without converting it to sugar. The heating is usually in stages, the temperature being held for some time at specified temperatures to give the enzymes time to act.

The initial process in brewing is mashing. The dried malt is milled to crush the husks so that the starches can dissolve more easily. The milled malt and water are put into the mash tub (No. 7, Fig. 130) where a series of controlled time-temperature treatments changes favor the action of enzymes on the proteins and starch, the latter being converted to fermentable sugars. The boiled adjunct from the cooker (No. 6) is added during the mashing, and thoroughly mixed in. The mash mixture, now

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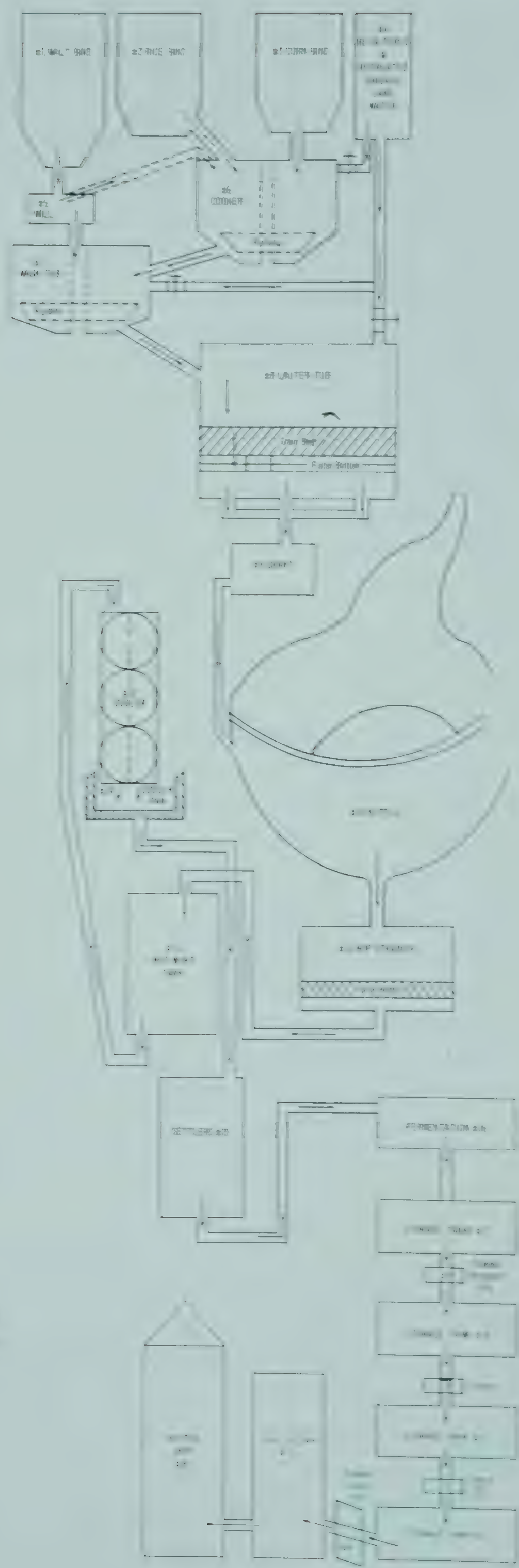


Fig. 130. Flow Diagram of the Brewing Process

called wort, then passes to the lauter tub (No. 8), which has a false bottom. The grain husks collect on this false bottom and form a filter bed, through which the sugar-containing liquid, called wort, is strained.

The clear liquid goes to the grant (No. 9) and then to the kettle (No. 10) where it is boiled for about two and a half hours, with addition of hops and (usually) corn sugar (dextrose). During boiling some of the hydrolyzed protein and the albumin are coagulated, the enzymes are destroyed and the liquid is sterilized. When the boiling is finished the hot wort is strained in the hop strainer (No. 11) to remove the leaves and stems of the hops, and then collected in the hot wort tank (No. 12). After cooling in the cooler (No. 13) and the cooler pan (No. 14), the yeast is mixed in and the mixture pumped to the settlers (No. 15) where it remains for 10 or 12 hours. After this the wort is pumped to the fermentation tanks (No. 16) where it remains until fermentation is complete and the sugars have been converted to ethyl alcohol and carbon dioxide. Storage, addition of chillproof (to hydrolyze β-globulin and prevent its precipitation on chilling) and carbonation follow (see Fig. 130).

There are several different types of beer, the differences being determined by the proportions of ingredients used and details of preparation. Most beers are produced by bottom fermentation, that is, with a yeast which sinks to the bottom of the tank during fermentation.

The term "lager beer" simply means that the beer has been aged after fermentation. Pilsener beer is a pale beer having a high hop rate and a very stable head. Munich, or Munchener beer is darker and sweeter than Pilsener and has a more pronounced malt flavor, due not only to use of a darker malt but also to a lower hop rate. Bock beer is a traditional spring time beer, being brewed in the winter. It is darker in color and usually sweeter and fuller bodied than other types. Caramelized or roasted malt is used in its preparation.

The principal beers produced with top fermenting yeast are ale, porter and stout. The distinction between bottom- and top-fermenting yeast will be described in detail in a later section of this chapter.

RAW MATERIALS

The selection of the proper raw materials is vital to the brewing industry, as it is impossible to brew a superior product from inferior starting materials. Some pertinent information regarding raw materials will be briefly discussed.

Barley

Two factors are responsible for the use of barley as the primary cereal for brewing: (1) it can be grown in a great variety of climatic conditions.

and thus is found all over the world, and (2) its straw-like husk makes it easier to process. The husks are not removed by threshing, and therefore protect the embryo during malting. They also assist in the clarification of wort by forming an efficient filter bed.

The two main types of barley are the two-rowed and the six-rowed varieties. The two-rowed barleys, *Hordeum distichum*, are considered in Europe to be the best for brewing. They are generally sown in the early spring. In the United States, these barleys are cultivated in the Pacific Northwest. Six-rowed barleys, *Hordeum hexastichum*, known as winter barleys because they are sown in the fall, are the most important grown in North America, and are extensively used for brewing. Barley grown in the Red River Valley is considered best for this purpose.

Present practice is to select a pure line and strain of barley, having known malting characteristics. A more detailed discussion of barley for malting will be found in Chapter 18.

Other Grains and Sugars

Rice and corn are often used as adjuncts in brewing, especially when a pale color is desired. The starches of these grains must be boiled before they can be attacked by the malt enzymes. Rice is used in the form of grits, which are broken grains obtained in the course of dehulling and polishing. The lipid content of the rice used for brewing should not exceed 0.5 to 0.7 per cent. Pre-boiling of corn can be avoided by using flakes, obtained by passing de-germed moistened ground meal between heated cylinders to gelatinize the starch. The fat content of the flour should not be over one per cent, and the fat must not be rancid, as otherwise free fatty acids would pass into the beer.

Dextrose is often added to the kettle to increase the amount of fermentable sugar. Commercial dextrose contains variable amounts of dextrins, which are not objectionable, as they give the beer a mellow flavor. The dextrose used should have a neutral reaction in aqueous solution, and should contain no iron or starch.

Hops

The hop, *Humulus lupulus*, is a perennial climbing plant and carries male and female influorescences on separate plants. Only the female ones are used in brewing. The flowers contain small lupulin glands which secrete the bitter resins and essential oils. Hops are picked in late August or early September, and must be dried as rapidly as possible to a moisture content of 12 to 13 per cent to prevent oxidation and polymerization of the essential oils. However, the temperature should not rise above 122°F. during the drying.

The hops grown in Czechoslovakia are considered to be the finest. In the United States, hops are grown mostly in Oregon, California, Idaho and New York. American hops are characterized by a rather fruity flavor. The average chemical composition of kiln-dried hops, as given by De-Clerck (1957), is shown in Table 109.

TABLE 109

COMPOSITION OF DRIED HOPS

	Per cent		Per cent
Moisture	12.5	Ether extract (mostly resins)	18.3
Ash	7.5	Tannin	3.0
Cellulose (gross)	13.3	Nitrogenous matter	17.5
Essential oils	0.4	Non-nitrogenous extract	27.5

From the standpoint of brewing, the important constituents of hops are the resins and the essential oils. Two resins are known: humulone (α-acid, α-resin) and lupulone (β-acid, β-resin). It has been shown by Rigby and Bethune (1952, 1953 and 1955) that humulone is a mixture of three closely related substances, called humulone, cohumulone and ad-humulone. The structure of these compounds has been elucidated by Howard and Tatchell (1954). Lupulone also is a mixture of at least two related compounds, called lupulone and colupulone, and probably a third compound is present. Structures for the first two compounds have been proposed by Riedl (1954) and Howard and Pollock (1954). These resins are responsible for the bittering and antiseptic powers of hops, and seem to be peculiar to this plant. During storage the resins are progressively oxidized and polymerized.

The essential oils of hops belong to the terpene group of hydrocarbons. They consist chiefly of myrcene and humulene (α-caryophyllene), with smaller amounts of other terpenes. These oils are also subject to resinification and polymerization when the hops are stored.

Another important component of hops is tannin. This has been found by Vancraenenbroeck and Lontie (1955) to consist of a mixture of at least three different groups of substances, including flavanols and leuco-anthocyanins. Harris (1956) has detected a number of individual compounds by means of paper chromatography using different solvents. Hop tannin is converted to reddish-brown phlobaphene on oxidation, behavior which is characteristic of catechol tannins.

Hops for brewing are selected chiefly by their external appearance and place of origin. Chemical analyses for moisture content and resins are usually carried out.

Water

Water is of the utmost importance in brewing, as its salt composition has a pronounced effect on the character and flavor of the beer brewed with it. The direct effect of the salts on the flavor of the beer is slight, for the reason that their amount is small in comparison to the total mineral content of the beer. However, different salts affect enzymatic and other reactions, as well as the solubility of the malt proteins, in different ways, thus exerting a powerful indirect effect on the palate. The salts are in the form of ions in a very dilute solution, so that it is inaccurate to speak of specific salts being present. The individual ions and their quantitative relationships to each other are the determining factors in the suitability of the water for brewing.

A high pH of the wort must be avoided, as it leads to uneven saccharification during mashing, difficulties in the separation of the wort from the spent grain (resulting in a low yield of extract) and incomplete coagulation of the proteins during boiling. It also results in a sharper bittering flavor from the hops and a biologically unstable beer susceptible to infection with lactic organisms. The pH of the water depends on the relative proportions of free carbonic acid and bicarbonate ions. The pH of the water has, in itself, little effect on the acidity of the wort, as the free carbonic acid is decomposed to carbon dioxide (most of which escapes) and water on heating. The acidifying effect of the water on the wort is due primarily to the reaction of calcium ions with secondary phosphate ions derived from the malt, according to the equation:

$$3\,Ca^{++} + 2\,HPO_4^{--} = Ca_3(PO_4)_2 + 2\,H^+.$$

The tertiary calcium phosphate formed is insoluble and precipitates out. The reaction does not, however, go to completion. This effect of calcium ions is discussed further in the section on mashing. Calcium ions also combine with proteins to form undissociated complexes and free hydrogen ions:

$$\text{Protein-}H_2 + Ca^{++} = \text{Ca-proteinate} + 2\,H^+.$$

Similar but less pronounced effects are produced by magnesium ions, but only during boiling in the kettle, because of the greater solubility of magnesium salts.

The mechanism of the action of other ions is not fully clear, but a brief description of some of their effects can be given. Sulfate ions give a drier, more bitter flavor, while chloride ions result in a mellower and softer taste. Too much iron causes degeneration of the yeast, and nitrites are also toxic to it. As nitrates are partially reduced to nitrites during fermen-

tation, they should not be present in amount larger than 25 p.p.m. Sodium ions give a disagreeable flavor, and in the presence of high bicarbonate ion concentration give high alkalinity.

The specific treatment necessary to adjust a given water to the desired composition will depend, of course, on the original composition. A hard water should be softened by one of the usual processes, but other treatments cannot be generalized. The final composition desired depends to a large extent on the type of beer to be brewed. The salt composition of the water used for several well-known types of beer, as listed by DeClerck (1957) and given in Table 110, shows some of the variations. The

Table 110

COMPOSITION OF VARIOUS BREWING WATERS
(Mg./1000 Ml.)

	Pilsen	Dortmund	Munich	Burton
Total solids after evaporation	51	1,110	284	1,790
Calcium (CaO)	9.8	367	106	520
Magnesium (MgO)	1.2	38	30	145
Sulfates (SO_3)	4.3	240	7.5	756
Chlorides (Cl)	5.0	107	2.0	34
Nitrates (N_2O_5)	Trace	Trace	Trace	22

water used for brewing in the United States generally has pH 6.0 to 7.0, 100 p.p.m. calcium and magnesium carbonates, 250 to 500 p.p.m. calcium sulfate and 200 to 300 p.p.m. sodium chloride.

As for water used for other purposes in the brewery, its specifications depend on the use to which it is put. Water for boiler feeds and attemperator coils should be soft, while water used for washing the plant equipment must be biologically sterile.

MALTING

A complete discussion of the malting process is given in the preceding chapter. A summary of this discussion is presented here for the sake of convenience. After harvesting, the barley is cleaned, dried (if necessary) and stored. To prepare the malt it is steeped in water for about 60 to 80 hours until it reaches a moisture content of 42 to 48 per cent, with aeration to be sure that enough oxygen is present for the growing embryo. The steeping liquor is changed frequently to remove micro-organisms, and the temperature should not be allowed to rise above about 58° F.[1] When the steeping is finished, the liquid is drained off and the barley is spread in a thin layer on the malting floor for germination.

[1] In brewing technology, temperatures are expressed as degrees Réaumur (°R). Zero on the Réaumur scale is equal to zero on the Centigrade scale. One degree Réaumur is equal to 1.25 degrees Centigrade, or 2.25° Fahrenheit.

During germination there is development of the complete enzyme systems for hydrolyzing starch to maltose and dextrins, degrading slightly soluble protein to simpler substances and hydrolyzing organo-phosphates to soluble phosphates. Some of these enzymes are present in unmalted barley in active form, some are present but closely bound up with other substances so that they cannot act, and others are formed during germination. Beta-amylase in barley is bound to the albumin proteins, but is liberated during malting by the action of proteolytic enzymes. Alpha-amylase is formed during germination. Cytase is active during germination, and plays an important part by hydrolyzing hemicellulose and rendering the endosperm cell walls permeable to other enzymes. Proteolytic enzymes are active, and the proportion of nitrogen soluble in dilute saline solution is about doubled during malting, while the proportion of non-coagulable nitrogen increases from about 9 per cent in barley to 30 per cent in malt. Other enzymes, such as phosphatase and oxidases, are also active.

Germination is allowed to continue for about six days and the malt is then dried by kilning. This is done both to arrest germination and to give the malt the flavor desired in the beer to be brewed from it. Care is taken not to inactivate the enzymes. They are protected by removing most of the moisture (all but about ten per cent) at below 122°F., and then heating to over 176°F. but not over 221°F.

MASHING

The object of mashing the malt and adjuncts is to bring into solution the relatively small quantities of substances which are soluble without enzyme action, and to change insoluble substances into soluble ones through enzyme action. The enzymatic reactions have already been initiated during malting, but are speeded up and controlled by regulating the temperature during mashing. For example, the ratio of starch breakdown during malting to that during mashing is about 1 to 10. The chemical structure of the starch, proteins, gums, pectins, etc. is changed in such a way that the finished wort contains 10 to 14 per cent total extract and no starch or dextrin giving a color with iodine. The pH should be 5.2 to 5.5, and must be regulated during mashing for optimum conversion of starch to sugars and to prevent turbidity caused by complex nitrogenous substances resulting from incomplete breakdown of proteins. Beers brewed from worts that are too alkaline show increased color and lack of stability.

The pH is controlled by adding lactic acid, mineral acids or calcium sulfate (gypsum) to the mash. The calcium sulfate converts phosphates in the malt to acid phosphates. Malt contains about one per cent phos-

phates (calculated as PO_4). Twenty per cent of this is soluble phosphate, of which about half is present as alkaline phosphate and the other half as acid phosphate. The alkaline phosphate must be changed to acid phosphate in order to provide buffer action for regulating the pH. The calcium sulfate reacts with the alkaline phosphates according to the equation:

$$3CaSO_4 + 4K_2HPO_4 = 2KH_2PO_4 + 3K_2SO_4 + Ca_3(PO_4)_2$$

Another function of the calcium sulfate is to prevent the conversion of acid phosphates to alkaline phosphates by the calcium carbonate present in the water, according to the equation:

$$4KH_2PO_4 + 3CaCO_3 = Ca_3(PO_4)_2 + 2KHPO_4 + 3H_2CO_3$$

The pH of the mash immediately after mixing with soft water is about 5.8 and the titratable acidity is about 0.05 per cent. The acidity at once begins to increase due to liberation of acid phosphates, lactic acid and other acids, such as amino acids, from the malt. The mash may be held at a temperature of about 95°F. for 30 to 60 minutes to promote acidification. If held too long at this temperature, butyric fermentation may result. This period is known as the "lactic acid rest" and may be omitted if an outside acidifying agent, such as lactic acid, is used.

Subsequently the temperature is increase by stages, by means of steam and by adding adjunct mash from the cooker at appropriate times. "Rests" at specified temperature levels favor specific enzymatic reactions.

The optimum degradation of proteins occurs between 113 to 140°F., while the greatest conversion of starches to fermentable sugars takes place between 140° to 149°F. The group of enzymes converting starch into dextrins and maltose is called "diastase." The separate enzymes known to be present in this group are α-amylase and β-amylase. It was suggested by Waldschmidt-Leitz and Mayer (1935) that a third enzyme, called amylophosphatase, was the enzyme responsible for the liquefaction of starch during mashing, by splitting inorganic phosphates from starch without saccharification. The present view (DeClerck 1957) is that this liquefaction is due to the action of α-amylase. During mashing liquefaction is pronounced at 122° to 176°F., with an optimum range of 158° to 167°F. Enzymes of fungal and bacterial origin, which are sometimes used to assist liquefaction of unmalted cereals, have high liquefying power and are destroyed at 194°F.

In order that the starch can be liquefied in a reasonable length of time, it must be gelatinized. The temperature of gelatinization varies with the type of starch and the size of the granules. For example wheat starch gels at about 140°F. while rice starch gels at 176° to 185°F. Gelatiniza-

tion is accompanied by a sharp rise in viscosity, but this decreases again on liquefaction.

Starch is hydrolyzed by both α- and β-amylases. Optimum conditions for β-amylases are 122° to 145°F. and pH 4.7 to 5.3. It is destroyed at temperatures over 172°F. It is already quite developed in ungerminated barley, but suffers during the kilning of the malt because of the high temperature. It splits off maltose directly from the starch molecule, leaving behind a compound of the amylo-dextrin type. While sugar formation from up to 60 per cent of the original starch proceeds rapidly, the iodine test continues to be positive for a long time, and with pure β-amylase complete conversion may never be attained. During mashing the length of time the mash remains at temperatures favoring β-amylase activity 140° to 149°F. determines the amount of maltose formed, and thus the alcohol content of the finished beer.

The α-amylase has optimum activity at 158°F. and pH 5.7. It is more resistant to high temperatures but less resistant to low pH than β-amylase. It is practically inactive in ungerminated barley. Hydrolysis of starch by α-amylase leads chiefly to the formation of dextrins of the type giving a negative iodine reaction. Thus a high mashing temperature (above the optimum for β-amplase) will result in wort having high dextrin content and low fermentable sugar content, yielding low alcoholic beer.

Beers low in alcohol because of high dextrin content are not so palatable as beers which have a higher alcohol content owing to processing. In order to keep the amount of fermentable sugar low the temperature of the mash must be raised quickly from 122° to 158°F. to suppress β-amylase activity, and this rapid rise prevents formation of the intermediate protein degradation products which are necessary as yeast nutrients and for adding body to the beer.

Starch degradation products other than maltose and dextrins are present in wort, but the exact mechanism of their formation has not been clarified. Enzymes other than the diastase group mentioned seem to be present in malt. Maltase is present in detectable amounts, but is largely denatured by heat during the kilning. The application of paper chromatography in brewing, introduced by Harris *et al.* (1951) and developed and simplified by McFarlane and Held (1953) has shown the presence of many different carbohydrates. These have been classified as higher dextrins, maltotetraose, maltotriose, maltose, sucrose, glucose and fructose.

In addition to starch hydrolysis, an important function of mashing is to bring about changes in the proteins present in malt. American six row barleys contain 12 to 14 per cent protein, of which roughly two-thirds is permanently insoluble. The remaining one-third, or about 3 to 5 per cent of dry substance, plays an important part in brewing. The proteins

in brewing adjuncts such as grits, flakes etc, are inert as far as mashing is concerned. The boiling of the adjuncts in the cooker seems to coagulate the portion of these proteins which might otherwise be soluble.

During mashing part of the insoluble malt proteins are converted to soluble ones, but a small fraction of the dissolved proteins are subsequently coagulated when the wort is boiled in the kettle. The balance of the dissolved protein material is unaffected by boiling, and is therefore known as permanently soluble protein.

Several different proteolytic enzymes (proteinases) are present in malt, but their exact number and nature are not known. They break the soluble, complex proteins down into simpler compounds of medium molecular weight, known as albumoses, peptones and polypeptides. These products have a very favorable influence on the palatability and foam of beer. It is essential that all of the original high molecular weight soluble protein be degraded, as otherwise it will cause turbidity and haziness in the beer. The proteinases have an optimum temperature range of 122° to 140° F. and an optimum pH range of 4.3 to 5.7. Further degradation of the medium molecular weight products to peptides and amino acids is brought about by a group of enzymes known as peptidases. These low molecular weight products are important as nutrients for the yeast. However, an excess of these compounds may cause sluggishness or degeneration of the yeast. They also tend to increase the surface tension and decrease the foam stability of beer. High mashing temperatures favor the formation of peptones while lower temperatures favor the formation of peptides and amino acids.

The temperatures and time intervals in a typical mashing process are as follows:

The *albumin* or *protein rest* is at 113° F. for 30 to 60 minutes. During this period the proteinases are very active, forming low molecular weight nitrogen compounds, such as amino acids, amides and peptides, from the proteins. Beta-amylase, splitting maltose off from starch is only moderately active. Acidification and formation of buffering compounds occurs.

The *sugar rest* is at 133° to 144° F. for 5 to 30 minutes, or may be entirely omitted. This temperature is near the optimum temperature for β-amylase, which is thus very active. Alpha-amylase, which forms dextrins, is moderately active. Proteinases are very active, but at this temperature produce more medium molecular nitrogen compounds than amino acids. For beers of restricted alcohol content, this temperature range should be passed over as quickly as possible.

The *dextrinizing* rest is at 136 to 162° F. for 15 to 45 minutes. The dextrin-forming α-amylase is very active, while maltose production is much reduced. The proteinase forming medium molecular compounds

is somewhat active, while that forming low molecular compounds is only slightly active.

Conversion, is at 162° to 167°F. for 10 to 20 minutes, depending on the malt and previous mashing procedure. This is the optimum temperature for quick and complete conversion of starch to dextrin by α-amylase. The conversion may be carried out at 154° to 162°F., instead, if desired. The temperature should not be higher than 167°F., or the diastase (amylases) may be destroyed.

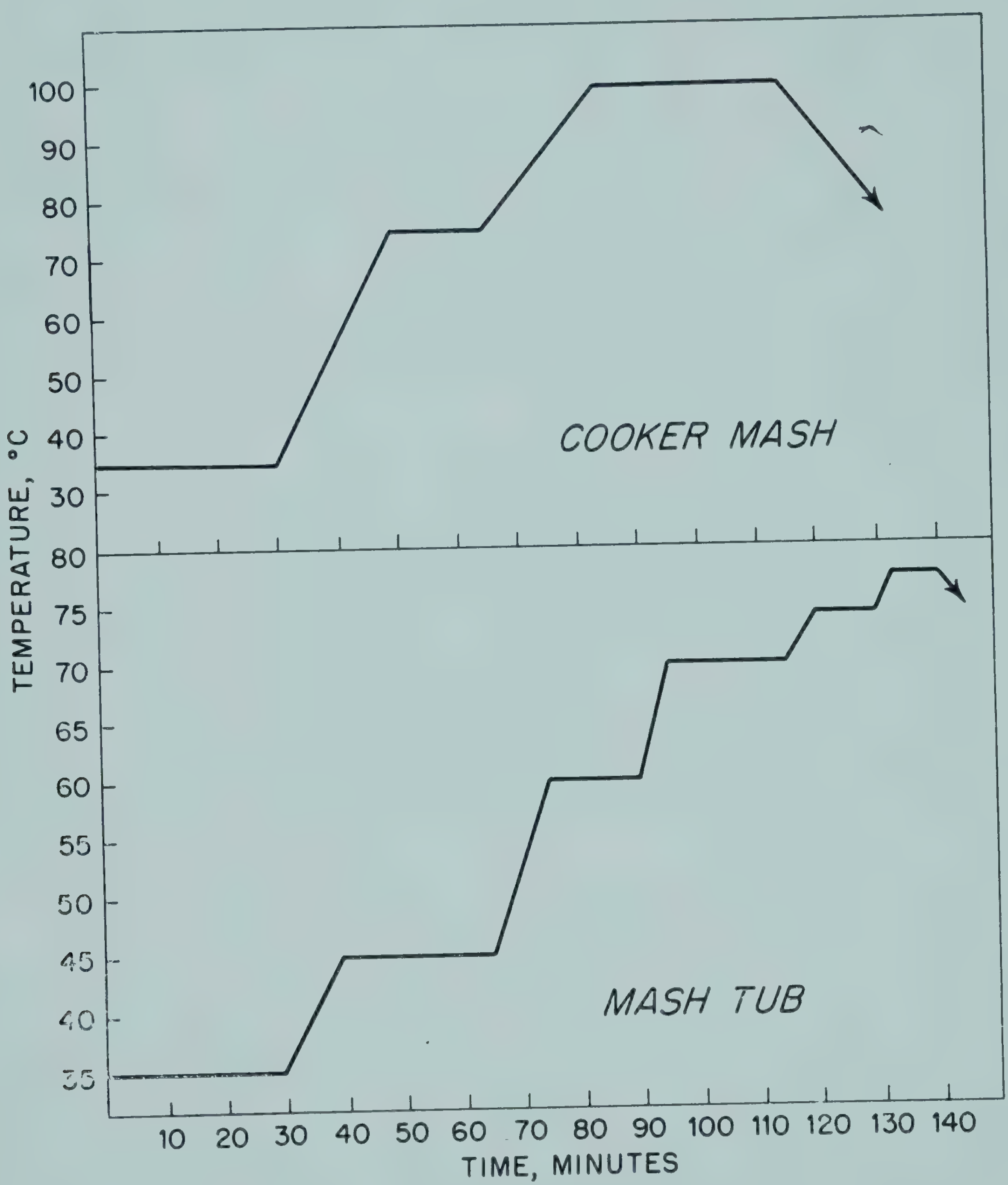


Fig. 131. Mashing Schedule for Cooker and Mash Tub

The Mashing-off Temperature is usually 167° to 176°F., and is held for 5 to 10 minutes. At this temperature most of the enzymes are inactivated, although α-amylase retains slight activity. The mashing-off temperature may be varied somewhat, depending on the desired alcohol content of the finished beer. For medium to high alcoholic beers a low mashing-off temperature may be chosen, because maltose formation during sparging

(subsequent washing of mash residue to remove wort) is not objectionable. A higher mashing-off temperature 172° to 174° F., is used for low to medium alcoholic beer, to keep maltose formation within the desired limits. High mashing-off temperatures make the wort less viscous and facilitate running off (wort separation), but too high a temperature may lead to belated but incomplete action on previously unconverted starch particles, causing turbid, slow-running worts and starch turbidity in the cellar. With western malts it is advisable to keep the mashing-off temperature at 165° to 167°F.

The mashing schedule is shown in graph form in Fig. 131.

CLARIFICATION OF THE WORT

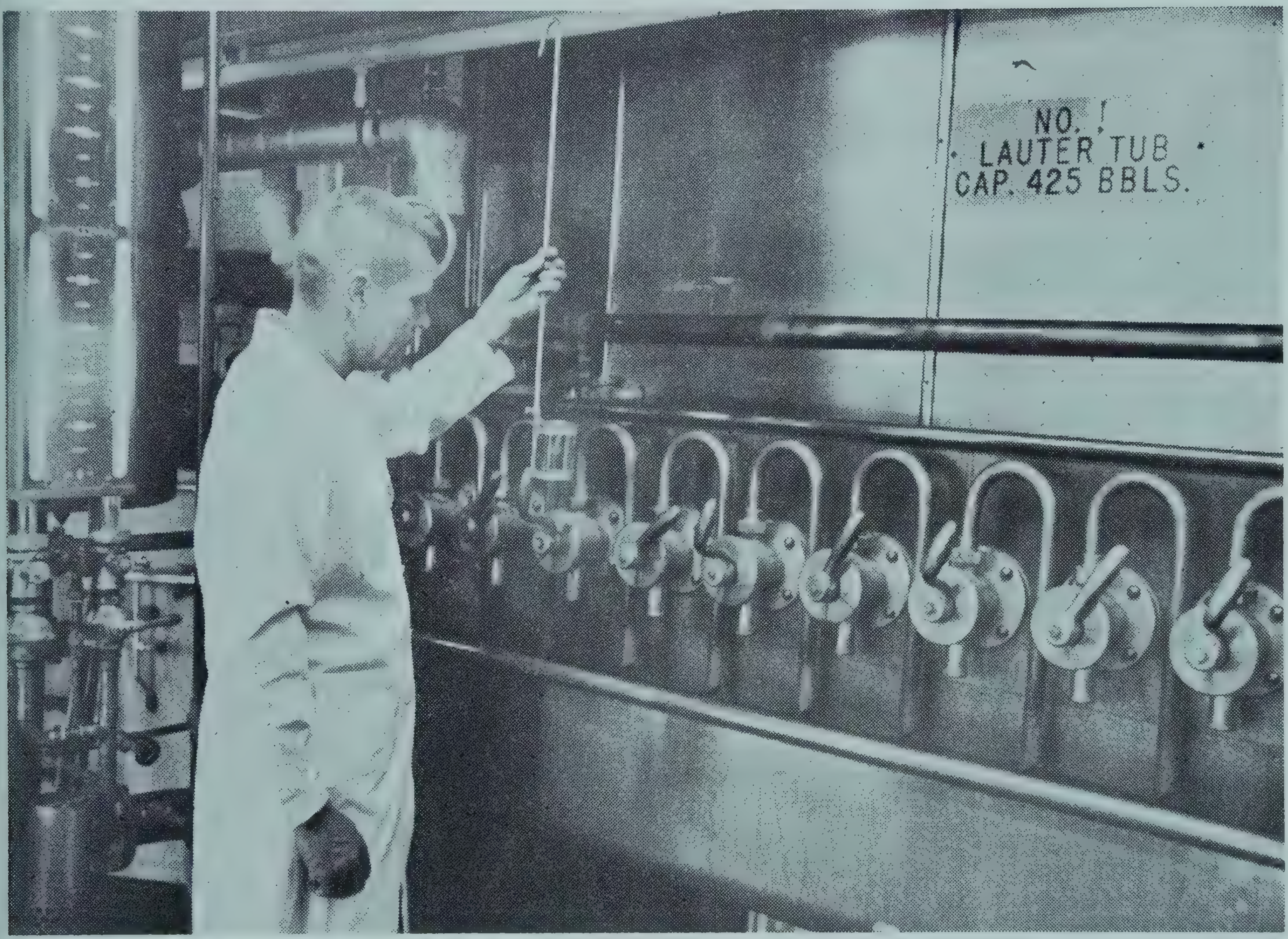
After the mashing process is completed, the water-soluble materials must be separated from the spent grain. This is accomplished by filtering the liquid through a bed of the spent grain supported by a false bottom (made of perforated plates). The filtration may take place in the mash tub itself, in a separate vessel known as a lauter tub, or in a filter press.

Filtration in the mash tub is rather inefficient, and is not common practice. Most frequently the filtration is carried out in the lauter tub. The mash is pumped into the tub and allowed to stand for about half an hour to let the spent grain settle and form a bed on the false bottom. Then taps leading from the bottom of the tub are opened and the wort is allowed to flow into the grant, a vessel in which the wort can be inspected and from which it can be transferred either to the kettle or back to the top of the lauter tub. The wort coming through into the grant during the first 10 to 15 minutes is usually opalescent, and is pumped back into the lauter tub to be refiltered. As soon as the filtered wort is clear, it is transferred to the kettle. This fraction is known as the first wort.

The process is continued until the runnings again appear opalescent and the rate of flow decreases, indicating that almost all of the liquid has run through. At this point the taps are closed. However, the filter bed still contains a good deal of extract which must be recovered. This is done by spraying hot water onto the filter bed, raking it to mix it thoroughly with the water (mashing over), allowing the spent grain to settle again, and drawing off the liquid as before. This process is called sparging. It is repeated until the last wort contains about one per cent but not less than 0.75 per cent extract. During sparging, the filtered liquid is pumped back as before until it comes through clear.

The sparging conditions must be controlled to ensure recovery of as much extract as possible without also extracting deleterious substances, such as bitter principles and tannins, from the husks. In order to main-

tain optimum conditions the sparging water is treated to prevent alkalinity, and the temperature of the sparge liquor should not be higher than 175°F. It should, however, not be much below this temperature, or the viscosity of the filter bed will increase to an extent such that the flow of the liquid is retarded. Fig. 132 shows a view of the grant and the lower part of a lauter tub.



Courtesy of Falstaff Brewing Corp.

FIG. 132. THE GRANT, SHOWING ALSO THE LAUTER TUB AND THE TAPS

In some large breweries, filtration in the lauter tub is considered to be too slow for efficient operation, and a plate and frame mash filter is used instead. These filters are constructed similarly to the filter presses used in sugar refineries, but high pressure is not used. The filter consists of hollow frames alternating with grooved plates covered with filter cloth. The wort passes through the filter cloth into the grooves and then through faucets into a collector similar to a grant. Sparging is carried out by passing the brewing water either from the pressure side or the inlet side of the filter press. A flow diagram of such a filter is shown in Fig. 133.

BOILING OF WORT

The boiling of wort is carried out to sterilize and stabilize it, as well as to extract the constituents from hops which give beer its characteristic

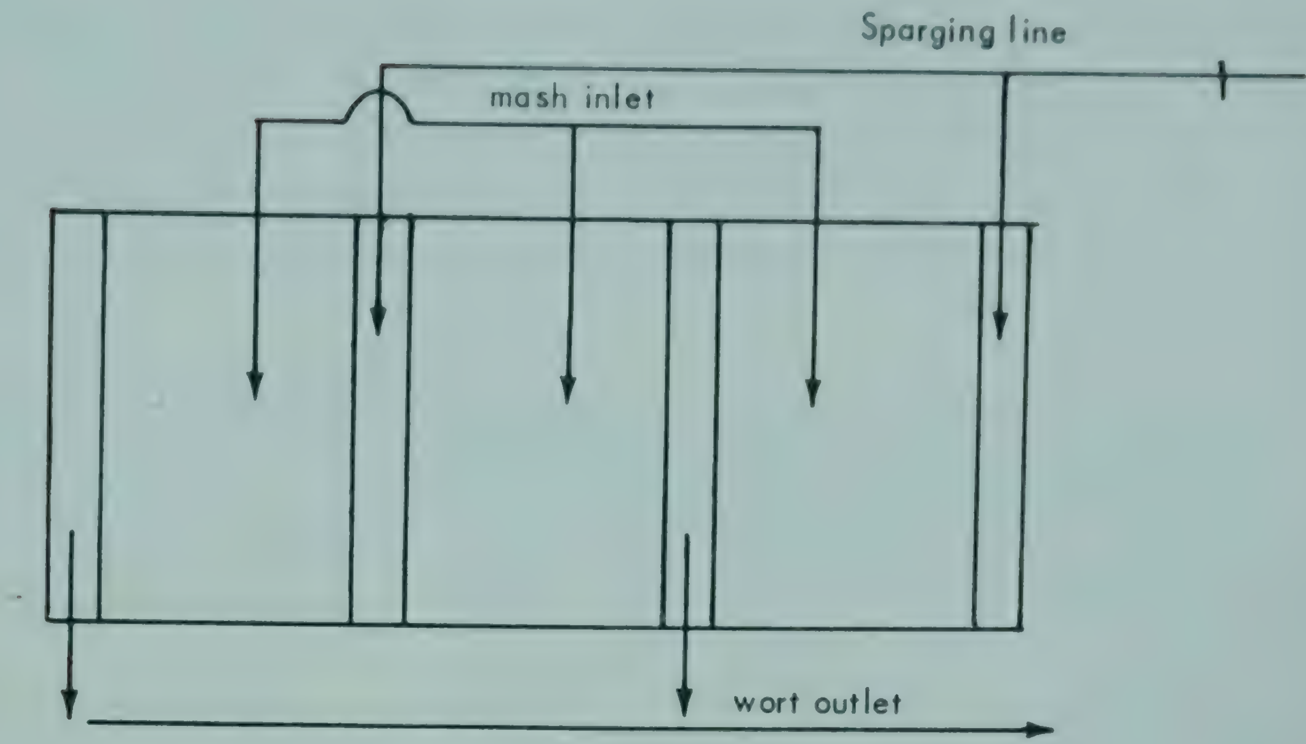


FIG. 133. FLOW DIAGRAM OF A WORT FILTER

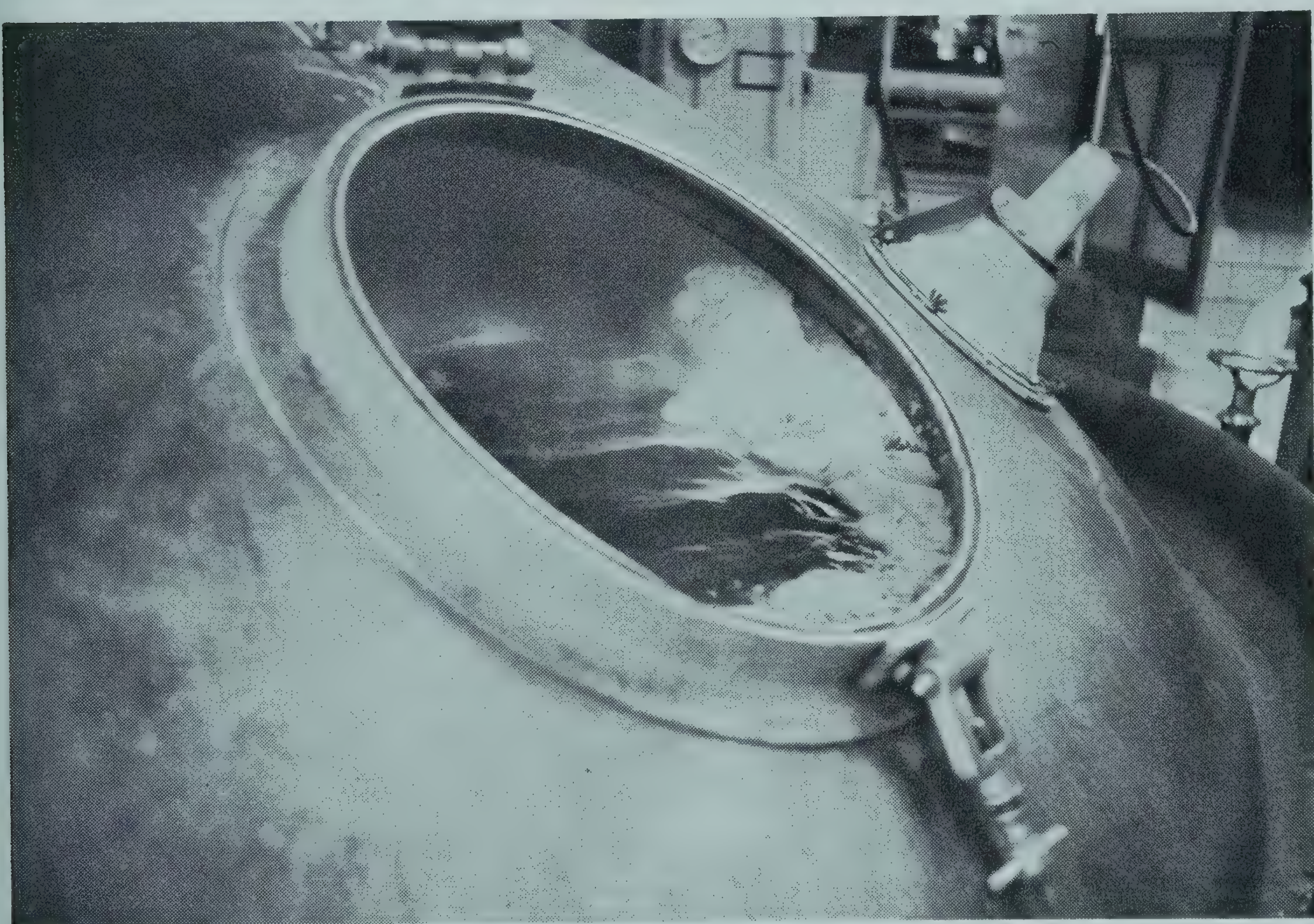
Courtesy of Falstaff Brewing Corp.

FIG. 134. ADDING HOPS TO THE BREW KETTLE

flavor and aroma. Figs. 134 and 135 show hops addition and wort boiling.

The slightly acid pH of the wort contributes to the sterilization, and makes it unnecessary to raise the temperature above the normal boiling point. The enzymes are also destroyed at this temperature, thus preventing further breakdown of starch and proteins. Dextrose is sometimes added to the kettle to bring the fermentable sugars to the proper level.

During boiling unstable colloidal proteins are coagulated by the heat aided by tannins extracted from malt husks and hops. This is known as the "hot break." Care must be taken to coagulate as much of the unstable protein as possible. One important factor is the pH, which should be near the iso-electric point of the proteins. This is generally considered to be about 5.2, and the pH should reach this value near the end of the boiling period (the pH drops by about 0.2 to 0.3 pH unit during boiling). Thus the pH of the wort should be 5.4 or 5.5 at the start of



Courtesy of Falstaff Brewing Corp.

FIG. 135. WORT BOILING IN THE COPPER KETTLE

the boil. Vigorous boiling also aids in the coagulation of the proteins, as albumin particles, already denatured by heat, tend to accumulate on the surface of the wort around the steam and air bubbles, and agglomerate more easily because of their proximity to each other. Excessively vigorous boiling in an open kettle, however, may have detrimental effects, owing to conversion of coagulated proteins to soluble forms through oxidation.

Hops are added chiefly to furnish two kinds of substances: essential oils and resins. The resins are responsible for the typical bitter flavor of beer. They are insoluble in cold wort, but somewhat soluble in hot wort at its normal pH. As they are only very sparingly soluble in water, their

solubility in wort is attributed to their adsorption on the surface of stable colloids. Some of the resins are adsorbed on colloidal particles which are later precipitated, and thus are thrown out of solution again. This loss is greater at lower pH, so that the pH of the wort should not be allowed to fall below 5.2. During boiling the resins are partially hydrolyzed, oxidized and polymerized.

The essential oils of the hops are very volatile, and evaporate off during boiling. Therefore, if a good aroma is desired, more hops must be added near the end of the boiling period. Occasionally hop oil is added to the finished beer instead.

Hopping is a phase of brewing in which detailed scientific knowledge is rather scanty, and the best procedures for attaining the desired flavor and aroma remain an important part of the "art" of brewing.

Another change occuring during boiling is a darkening of the color, caused by a caramelization of sugar, formation of melanoidins and oxidation of tannin to phlobaphene. These changes are accentuated by high pH and excessive aeration. The reducing power of wort is increased during boiling by the formation of so-called reductones, which are tautomeric compounds. Aeration of the wort during boiling lowers its reducing power.

The usual period of boiling is about 2 to 2 1/2 hours. At the end of this time the hot wort is strained in the hop strainer and then cooled.

WORT COOLING

The hot wort must be cooled to well below 104°F. before fermentation, as higher temperatures will inactivate the yeast. The wort is cooled to 57° to 61°F. when top-fermenting yeast is to be used and to 43° to 46°F. for bottom-fermenting yeast.

During cooling two apparently anomalous conditions must be fulfilled: (1) care must be taken not to infect the wort with micro-organisms, as the temperature range between 104° to 68°F. is most favorable for their growth, and (2) enough oxygen must be dissolved in the wort to stimulate yeast growth. In addition, during the cooling the protein coagulated during the boiling, the "hot break," should be entirely eliminated and the turbid matter appearing during cooling, the "cold break," should be at least partly precipitated so that it does not remain colloidally suspended.

Modern brewery practice is to solve these problems by using closed coolers and pumping measured amounts of sterile air into the wort in the coolers. A common design is that of concentric pipes, the cooling liquid flowing through the central ones and the wort and air through the outer ones. Too much oxygen must be avoided, as an excess can result in oxidation of part of the coagulated protein, preventing efficient precipita-

tion. The proteins precipitate partly by agglomeration of oppositely charged particles, such as the positively charged derived albumins and the negatively charged nucleoproteins. If these particles are approximately in balance, precipitation will be nearly complete. Oxidation may change the charge on some of the particles, thus destroying the balance.

To minimize bacterial growth, the coolers are designed to cool the wort rapidly to below the optimum growth range. In the later stage of fermentation, the danger of infection is much less, as the disappearance of sugars and appearance of alcohol due to yeast action provides a less favorable medium. After fermentation, the temperature of the beer is kept low throughout the later processing, so that it remains essentially sterile, and it is finally pasturized.

FERMENTATION

Lager beer is produced with bottom fermenting yeast. For this the wort is cooled to 43° to 50°F. and pumped into a collecting tub or hot wort tank. It remains here for about four hours to give the turbidity (hot and cold break) time to settle out, and is then transferred to the pitching tub, leaving the sediment behind. Here it is pitched (mixed) with the required amount of yeast, usually $^3/_4$ to 1 lb. per barrel of wort, and the foam formed during mixing is skimmed off. After about 24 to 48 hours the "kraesen" appear. These are heads of foam caused by evolution of gases, which carry hop resins and nitrogenous material to the surface with them. As soon as kraeusen appear the wort is pumped to the fermentation tank, which can be either open or closed. Usually closed fermentors are used so that the carbon dioxide produced can be collected and injected back into the beer at a later stage in the processing.

The overall reaction occurring during fermentation is the conversion of fermentable sugars to alcohol and carbon dioxide. This being an exothermic reaction, heat is generated in the process.

$$C_6H_{12}O_6 \xrightarrow{\text{yeast}} 2CO_2 + 2C_2H_5OH + 22 \text{ calories}$$

Therefore the temperature will rise, but it should not be allowed to exceed 46° to 48°F. Temperature control is accomplished by coils in the tank, with cold liquid flowing through them. These coils are called attemperators.

The progress of the fermentation is followed by determining the amount of sugar present with a saccharometer. The saccharometer readings begin to fall almost immediately after the wort is pitched with yeast, and fall more rapidly as fermentation progresses. The fermentation becomes very active 15 to 18 hours after pitching and reaches its height 70

to 80 hours after pitching, with maintenance of this level for 48 to 72 hours. It then decreases in intensity, and fermentation is usually complete in 7 to 9 days. The rate of drop of the saccharometer readings is 0.2 to 0.5 per cent per day in the early stages, reaches 1.0 to 1.5 per cent per day in the later stages, and then falls slowly to about 0.10 per cent in the final stages.

Courtesy of Falstaff Brewing Corp.

FIG. 136. PITCHING YEAST IN A STERILE STORAGE AREA

During the active period the foam rises in height and becomes darker in color owing to hop resins, proteins, dead yeast cells, etc. When the rate of fermentation begins to decrease the head of foam starts to collapse because not enough gas is being produced to support it. With the decrease in fermentation less heat is generated and the rate of attemperation is moderated, but the temperature should not be allowed to rise above 59°F.

Fermentation is considered to be complete when the desired degree of sugar conversion (called attenuation) has taken place. If secondary fermentation during storage is desired, some sugar must remain; otherwise fermentation is continued to complete attenuation. When fermentation is complete the beer is cooled slowly to 39°F. and pumped off carefully, in a manner to avoid disturbance of the sediment at the bottom of the tank.

This sediment consists of three layers. The bottom layer is a sludge composed of materials settling out of suspension in the wort. The middle layer is the yeast crop, which is saved for later fermentations. The top layer is mostly hop resins. Yeast not required for brewery operation is filtered, dried and sold for use as stock feed and for human consumption. Fig. 136 shows a special sterile storage area for keeping yeast which is to be used for pitching.

While the overall process in fermentation, the conversion of sugars to alcohol and carbon dioxide, appears to be a simple chemical reaction, the whole process is a combination of complex reactions involving the metabolism of the yeast. Yeast is a unicellular organism, composed principally of water (about 75 per cent in pressed yeast), glycogen, protein, yeast gum, lipids and mineral salts. The action of yeast on wort during fermentation is due to enzyme action. Some of the principal enzymes in yeast are invertase, maltase, glycogenase, phosphatase, amidases, oxydoreductase, hexokinase, carboxylase, protease and peptidases. Not all of these enzymes are able to act upon external substrates. Several coenzymes are also present.

The growth of the yeast itself is a phenomenon separate from fermentation, but in brewing the two go hand in hand. The yeast nutrients are furnished by the wort. The essential classes of substances which must be present for yeast nutrition are mineral salts, sources of carbon, energy sources, nitrogen sources and growth factors. The necessary mineral salts are normally present in the wort, coming partially from the malt and partially from the brewery water. A small portion (about two per cent) of the fermentable sugar in the wort is utilized by the yeast as a source of carbon and also of energy, by fermentative breakdown within the cell. The nitrogen requirements are satisfied by the amino acids and peptides present—more complex protein fragments and proteins themselves cannot be metabolized. Yeast can synthesize many of the growth factors which it requires, the specific capacity varying from one strain of yeast to another. The factors which must be present in the growth medium appear to be present in normal wort, stemming from the malt, which is rich in the vitamin B complex and other growth factors.

The growth of yeast during fermentation can be divided into five well-defined phases: (1) a latent phase, lasting a few hours, during which occurs no significant visible changes in the cells; (2) a lag phase, with slow growth, lasting only a short time; (3) a logarithmic phase, with rapid increase in growth rate, this phase continues for about four hours at 64°F. but only eight minutes at 86°F. under ideal conditions; (4), phase of negative acceleration, during which the rate of reproduction falls slowly; and (5) stationary phase, in which the rate of multiplication is

approximately equal to the rate at which the cells die and autolyse.

Several changes take place in the wort during fermentation, in addition to the attenuation. The pH falls, due to formation of carbon dioxide and organic acids, mostly lactic acid. The normal pH after bottom fermentation is 4.2–4.4, or occasionally 4.0 or less, depending on the quantity of buffers present. The nitrogen content also falls by about one-third, due chiefly to the assimilation of amino acids and peptides by the yeast, and partly to precipitation of complex proteins caused by the lowered pH, the presence of alcohol, and concentration at the surface of the carbon dioxide bubbles and the yeast cells. At the end of fermentation the beer contains about 0.3 per cent dissolved carbon dioxide, and practically no dissolved oxygen. Hop resins are largely eliminated by the fall in pH, adsorption on the yeast cells and coagulation in the head. The bitter material in the head must be skimmed off carefully to avoid too sharp a taste in the finished beer. Finally, the color of the wort becomes paler during fermentation, partly because of eliminating of colored substances in the scum at the surface, partly because of the reducing action of yeast on oxidized tannin, and partly by the normal fall in color intensity accompanying the drop in pH.

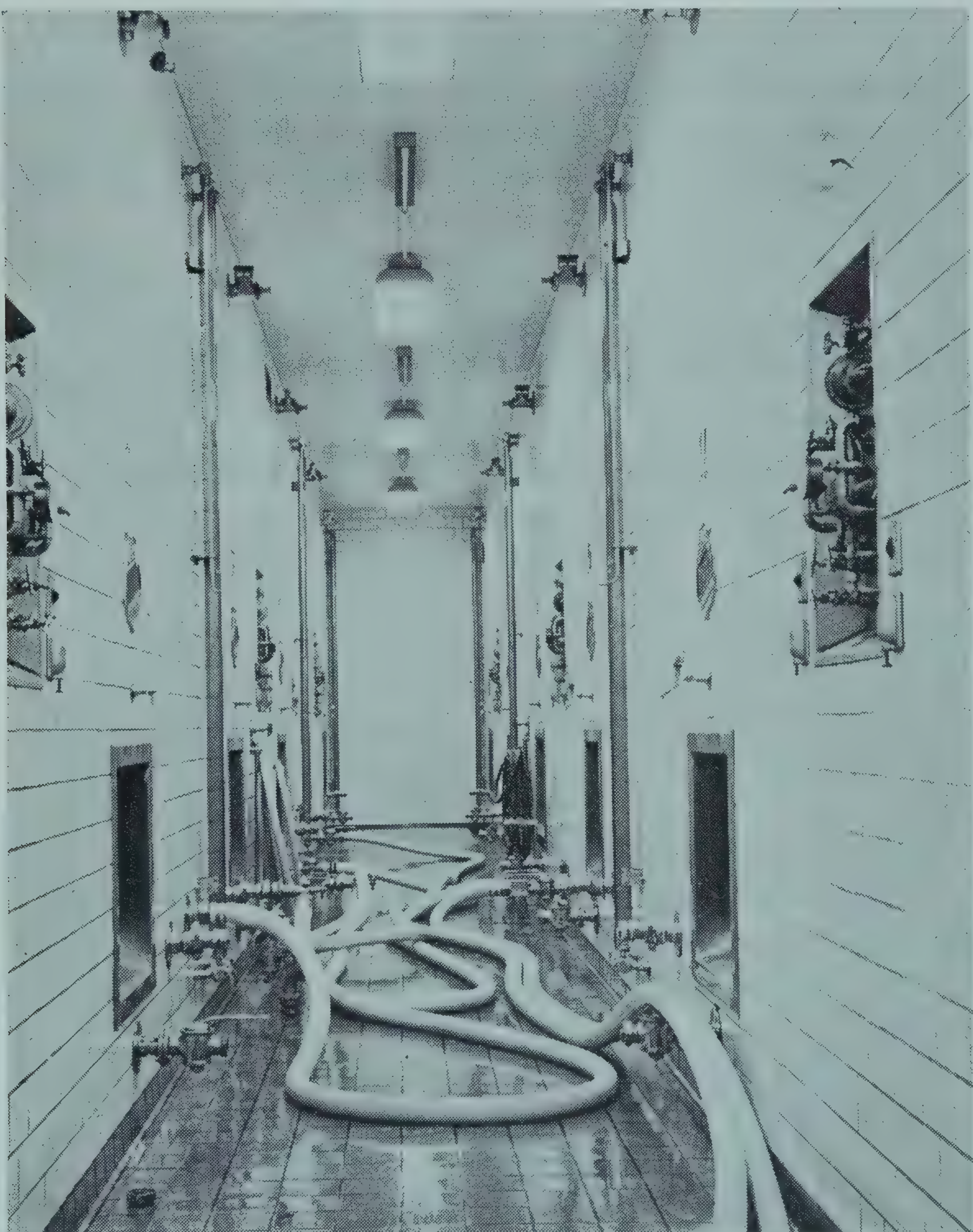
STORAGE

When the beer, at about 39°F., is pumped out of the fermentation tank, it passes through a cooler where it is quickly chilled to 32°F. and then sent through a diatomaceous earth filter. Diatomaceous earth is preferable to filter mass at this point, as the latter has a tendency to become clogged. The brilliant filtered beer is then pumped into pressure tanks in a storage cellar of the type shown in Fig. 137. Here it is stored at 32°F. and is carbonated with carbon dioxide previously collected from the fermentation tanks. In rare cases the beer is not chilled but is stored at 39° to 43°F., in which case secondary fermentation takes place. At 32°F. no further fermentation occurs, but the beer undergoes an important period of aging. During this time yeast cells and other insoluble nitrogenous materials settle out, and the flavor of the beer is improved and mellowed as a result of complex chemical changes involving aldehydes, esters and higher alcohols.

Periodically, the beer is transferred from one tank to another, with recarbonation at each transfer. The purpose of these operations is to flush out any dissolved air and also to permit slow and intimate contact of the carbon dioxide with the beer, so that it is not only mechanically held in solution but also adsorbed by the colloidal particles present. The beer is kept under 5 to 6 lbs. per sq. in. counter pressure during storage and

transfer. A period of about two weeks is considered sufficient for adequate carbonation.

Some time during storage the beer is usually chillproofed. When beer is chilled to low temperature, a colloidal haze appears, but it disappears again when the beer is warmed slightly. The nature of chill haze has been a subject of controversy for many years. Sandegren (1947) and St.



Courtesy of Falstaff Brewing Corp.

FIG. 137. CELLAR STORAGE TANKS BEHIND WHITE TILE WALLS

Johnston (1948) considered it to be composed of β-globulin degradation products and tannins. Its composition has been clarified by recent work of Biserte and Scriban (1953). Proteins (about 25 per cent) and tannins have been shown to be present, the protein fraction being an extremely complex mixture of degraded globulin-like bodies, hordein and glutelin derivatives. Chillproofing is a treatment designed to minimize the ap-

pearance of chill haze. Chillproofs include materials such as tannic acid added to precipitate the proteins, materials to adsorb them, such as certain types of bentonites, and proteolytic enzymes to hydrolyze them to more soluble fractions.

After its sojourn in the storage cellar, the beer is finished, and is ready for a final filtration followed by filling into casks or bottles.

A TYPICAL BREW

Although ingredients used and their proportions vary according to the type of beer and individual preferences, the following "recipe" for a typical brew will give an idea of the amounts of materials needed.

Cooker Mash

The cooker is filled with 3500 lbs. of grits (milled corn), 675 lbs. of malt, 70 barrels of water, 2.1 quarts of lactic acid and 3 lbs. of calcium sulfate. The mixture is brought to boiling.

Mash Tub

The tub is filled with 10,000 lbs. of malt, 100 barrels of water, 1.58 quarts of lactic acid and 2.0 lbs. of calcium sulfate. This is heated according to the mashing schedule, and at the end of the heating period the cooker mash is added.

Lauter Tub

The above mixture is first filtered through the spent grain bed without additions. For sparging, 3.2 quarts of lactic acid and 5.0 lbs. of $CaSO_4$ are added to the sparge water and 1.4 quarts of lactic acid and 2.0 lbs. of calcium sulfate during the mashover (raking of the grain bed to mix it with the sparge water).

Kettle

The clarified wort and spargings are filled into the kettle as they arrive from the grant. The filling takes about four hours. The mixture is then boiled for two and one-half hours with the addition of 16.0 lbs. of salt. and 4.25 lbs. of $K_2S_2O_5$. Hops are added in two portions as follows: 50 lbs. at 30 min. and 50 lbs. at 20 min. before the end of the boiling period. This mixture is added to the kettle over a period of 20 minutes. before the end.

Two hours before the end of boiling, mixing is started, in a separate vessel, of 1000 lbs. of dextrose and 5 to 6 barrels of water. The temperature should not be allowed to rise above 162°F. at any time during the

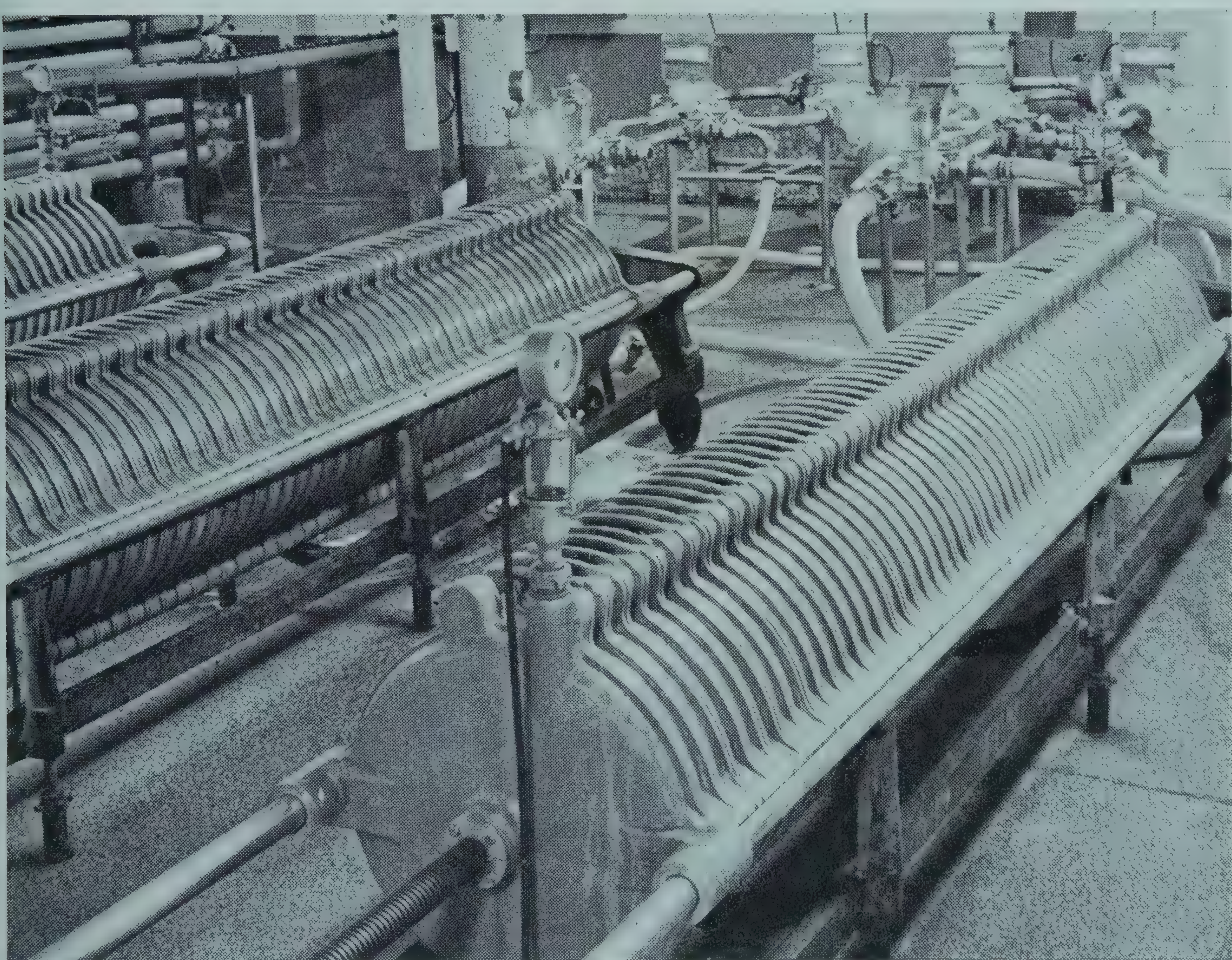
mixing. This mixture is added to the kettle over a period of 20 minutes, starting one hour before the end of the boiling period.

Cellar Additions

During storage 3 lbs. of $K_2S_2O_5$ per 850 barrels, 1 lb. of chillproof per 75 barrels and 5 lbs. of gum arabic per 100 barrels of beer are added. (A standard U. S. barrel of beer is 31 gallons.)

FILTRATION, RACKING AND BOTTLING

After aging the beer possesses its final flavor and aroma, but it is still slightly hazy. It is therefore given a final filtration through a pulp mass



Courtesy of Falstaff Brewing Corp.

Fig. 138. Multistage Filter for Final Filtration

composed of cellulose fibers mixed with about one per cent asbestos, through filter sheets or through diatomaceous earth. The type of filter usually used is shown in Fig. 138. This filtration is not a simple sieving process, as most of the particles present at this time are of colloidal size. Their elimination is due rather to adsorption on the filter mass. Thus not only particles which can be optically detected as a haze, but also other

substances having a high surface tension will be absorbed. On this account the final filtration removes some proteins, hop resins, coloring matter, higher alcohols and esters.

The beer is then racked into casks or filled into bottles or cans, and is ready for marketing. The filtration, racking and bottling should be carried out in a manner to avoid loss of carbon dioxide, infection and oxidation. To prevent loss of carbon dioxide, the beer is kept cold and racked or bottled against a counter pressure of carbon dioxide or air. Carbon dioxide is preferable, as a counter pressure of air may result in the dissolving of some air in the beer, leading to gradual oxidation. The danger of infection of the beer is minimized by sterilizing the filters and machinery and keeping them strictly clean.

Beer in bottles or metal casks is generally pasteurized to destroy infecting organisms, such as yeast and non-spore forming bacteria. Pasteurization is accomplished by heating the beer to 140° F. for a few minutes.

ANALYTICAL CONTROLS IN BREWING

Before the development of suitable analytical methods, brewing was entirely an art, and empirical methods for controlling quality were handed down from generation to generation. While many phases of brewing are still largely an art, and a thorough practical knowledge of the factors to be considered at every stage is indispensable, the brewer now has at his command a host of scientific analytical methods to aid in controlling quality and to detect a possible source of trouble before it becomes serious.

Chemical and physical analyses are generally performed on the raw materials used, on the intermediate products obtained during brewing and storage, and on the finished product. A complete listing of all the tests used is beyond the scope of this chapter, and only a few representative analyses will be given to indicate the nature of the examinations which may be carried out. Directions for carrying out most analyses in general use are given in "Methods of Analysis of the American Society of Brewing Chemists" (Anon. 1949), hereafter referred to as "A.S.B.C. Methods."

Typical reports for malt, hops, brewing syrups, and cereal adjuncts are given in Tables 111, 112, 113 and 114, respectively. The values in these tables were determined and reported in accordance with the A.S.B.C. Methods, with the exception of soluble protein (Table 111). Details concerning this determination will be found in the experimental section.

A complete analysis of a typical American beer is given in Table 115. The last column in this table, headed "Reference," indicates where the method for each determination can be found.

TABLE 111

MALT—PHYSICAL CHARACTERISTICS

Bushel weight (lbs.)		$39^1/_4$
Growth		
Length of acrospire (fraction of kernel length)	0–$^1/_4$	1 Per cent
	$^1/_4$–$^1/_2$	0 Per cent
	$^1/_2$–$^3/_4$	3 Per cent
	$^3/_4$–1	92 Per cent
	Overgrown	4 Per cent
Mealiness		
Mealy		95 Per cent
Half-glassy		4 Per cent
Glassy		1 Per cent

CHEMICAL ANALYSIS

Moisture, per cent	4.7
Extract in the finely ground malt (plato), per cent as is	74.20
Extract in the finely ground malt (plato), per cent dry basis	77.90
Conversion in minutes	5 Min.
Odor of mash	Aromatic
Degree of clarity	Clear
Speed of filtration	Normal
Color of laboratory wort, Lovibond, $^1/_2$ in. cell, Ser. 52	1.4–1.6
Diastatic power—degree Lintner, as is	124
maltose equivalent, as is	496
Total protein, as is, per cent	10.33
Total protein, dry basis, per cent	10.83
Soluble protein, as is, per cent	3.93
Soluble protein, dry basis, per cent	4.12
Ratio soluble/total protein	38.10

TABLE 112

ANALYSIS OF HOPS—PHYSICAL EXAMINATION

	Yakima	California Seedless
Cones		
Color	Light green	Light green
Luster	Dull	Dull
Size	Medium	Small–medium
Condition	Fair	Good—some wind whipped
Lupulin		
Amount	Plentiful	Plentiful
Color	Yellow	Yellow
Condition	Sticky	Sticky
Aroma	Aromatic	Aromatic
Leaves and stems (per cent)	0.6	0.2
Seeds (per cent)	4.9	0.1

CHEMICAL EXAMINATION

	Per cent	Per cent
Moisture	6.7	7.2
Resins		
Alpha resins	4.8	3.1
Beta resins	8.2	7.4
Gamma resins	1.4	1.6
Soft resins	13.0	10.5
Total resins	14.4	12.1
Brewing value $\left(\text{(Alpha resins} + \dfrac{\text{Beta resins}}{4}\right)$	6.8	5.0

Table 113

ANALYSIS OF BREWING SYRUPS—SUGAR

PHYSICAL CHARACTERISTICS
Samples A and B

Consistency, as is	Viscous—lumps	Odor, as is	None
Color, as is	Colorless	Taste, as is	Sweet

CHEMICAL ANALYSIS

	Sample A	Sample B
Clarity of 10 per cent solution	Clear	Clear
Color of 10 per cent solution	Colorless	Colorless
Specific gravity of 10 per cent solution	1.03200	1.03310
Extract, as is, per cent	83.0	86.0
Degrees Baumé	43.9	45.3
Moisture, per cent	17.0	14.0
Fermentable extract, as is, per cent	54.0	72.2
dry basis, per cent	65.0	84.0
Dextrose equivalent	No figures available	86.0
Iodine reaction	Negative	Negative
pH Value	5.4	5.4
Protein, per cent	.1	.01
Ash, per cent	.1	.01
Diastatic power	100	...
Dextrose, per cent	No figures available	86.0
Sucrose, per cent	No figures available	...

Table 114

ANALYSIS OF CEREAL ADJUNCTS

PHYSICAL CHARACTERISTICS

Color, as is	Buff
Odor, as is	Clean and normal
Husks, germs, etc.	Under 1.0 per cent
Mold	None
Weevils, etc.	None

CHEMICAL ANALYSIS

Moisture	Not more than 11.0 per cent
Oil	Less than 1.0 per cent
Extract, as is	79.0 per cent
Extract, dry basis	89.0 per cent
Time of conversion	15 minutes
Ash	2.0 per cent
Protein	8.0 per cent

These analyses may appear to be long and unnecessarily detailed. While they are numerous when considered individually, certain groups of tests serve to point out the most subtle off-taste characteristics, such as sweetness, bitterness and oxidation. Other groups will point out deviations in characteristics such as foam stability and shelf life. For example, the group of analyses associated with foam stability includes surface tension, surface activity, foam sigma, foam density, and protein and sugar distribution. Not all of the tests are conducted on an individual beer sample.

In the case of bitterness, the pertinent analyses are sulfur dioxide, iron,

TABLE 115

ANALYSIS OF A TYPICAL BEER

Specific gravity[1]	1.01210
Beer Balling, per cent[1]	3.093
Saccharometer, per cent[1]	3.10
Alcohol by weight, per cent[1]	3.63
Alcohol by volume, per cent[1]	4.60
Real extract, per cent[1]	4.73
Extract of original wort (2A + E), per cent	11.99
Original balling, per cent[1]	11.80
Reducing sugars, per cent[1]	1.160
Degree wort sugar, per cent[1]	71.30
Degree attenuation, per cent[1] (real degree of fermentation)	60.00
pH[1]	4.35
Color, ° L.[1]	2.94
Air, cc.[2]	1.20
Nitrogen, cc.[2]	1.01
Oxygen, cc.[2]	0.19
Oxygen/air, per cent[2]	15.80
CO_2, per cent by wt.[1]	0.460
Acidity, per cent[1]	0.135
Erythro-dextrins (iodine reaction)[1]	0
Amylo-dextrins (iodine reaction)[1]	0
Dextrins, per cent[1]	2.73
Iron, p.p.m.[1]	0.175
Indicator-Time test, sec.[3]	290.
Surface tension, dynes[4]	46.00
Surface activity[4]	0.367
$CaSO_4$, p.p.m.[5]	256.00
NaCl, p.p.m.[5]	153.00
Foam sigma[6]	109.00
Foam density[6]	20.40
Tannins, p.p.m.[7]	55.40
Viscosity, c.p.[4]	1.057
SO_2, p.p.m.[8]	13.20
Ash, per cent[1]	0.148
Diacetyl, p.p.m.[1]	0.210
Copper, p.p.m.[9]	0.245
Fractional Carbohydrates, per cent[10]	
Glucose	0.001
Fructose	Trace
Sucrose	Trace
Maltose	0.10
Maltotriose	0.20
Maltotetraose	0.45
Higher saccharides	3.04
Total saccharides	3.83
Fractional Proteins, per cent[4]	
Total protein	0.299
High molecular	0.0710
Medium molecular	0.100
Low molecular	0.0951
Non-protein N	0.0290
High/total	23.30
Medium/total	33.20
Low/total	31.60
Non-protein/total	9.6
Calories[4]	168.30

[1] Anon. 1949.
[2] Roberts *et al.* (1947).
[3] Gray and Stone (1939).
[4] Any standard method.
[5] Stone *et al.* (1951).
[6] Gray and Stone (1940).
[7] Stone and Gray (1948).
[8] Monier-Williams (1940).
[9] Stone (1942).
[10] McFarlane *et al.* (1954).

copper, tannins, carbon dioxide, air and melanoidins. These substances are normally present in beer, but in very small amounts, well below the organoleptic threshold (the level at which a difference in flavor can be detected by tasting the beer). The approximate organoleptic threshold for each of these substances has been established, and is used to evaluate the analytical results. For example, if the amount of iron is 0.35 p.p.m. or below, no off-flavor can be detected, but a value of 0.70 p.p.m. will result in a distinct bitter flavor. If 0.35 p.p.m. are removed, the flavor will again be normal. Another example is sulfur dioxide, which is normally present in the amount of 3.5 to 8 p.p.m. This is below the organoleptic threshold of most beer drinkers, but if the amount is increased to 16 p.p.m. astringency will be noticeable to almost everyone.

With the threshold values established, it is easy to tell which substance or combination of substances is responsible for any off-flavor occurring, and the cause of the trouble can be corrected. Before accurate analytical methods were developed, correction of the trouble was necessarily a matter of trial and error, and the length of time needed to find the source of the deviation was largely a matter of luck. Even more important than correction of an existing off-flavor is the ability to detect any "creeping trouble" before it actually results in detectable change of flavor. For example, if the sulfur dioxide values for successive batches of beer showed a steady increase from 3.5 to 7 p.p.m. steps could be taken to find the reason for this increase and correct it before the organoleptic threshold was reached.

One of the most important factors affecting appearance, taste, foam stability and shelf life of beer is the oxidation of proteins in beer. It has already been pointed out that the proteins can be divided into groups according to their molecular weight, and that this factor must be taken into account during mashing. St. Johnston (1948) has classified the principal protein fractions of wort and beer as follows:

1. Protein T.—The chill-sensitive globulin tannin complex. Iso-electric point 6.4, completely soluble at 140° F. with solubility diminishing below this temperature.

2. Protein C.—The coagulable albumin. Iso-electric point 6.0, readily coagulated by heat.

3. Protein O.—The oxyprotein or nucleoprotein. Iso-electric point 3.9.

4. Fraction D.—Soluble fraction. Probably proteoses associated with dextrins.

At the pH of beer, about 4.3, the nucleoproteins will carry a negative charge and albumins a positive charge, so that mutual precipitation is possible.

A similar classification of protein fractions is that proposed by Lundin, as quoted by Pawlowski and Doemens (1932). He designates the fractions as A (high molecular weight), B (medium molecular weight) and C (low molecular weight).

The equilibrium between these protein fractions can easily be upset by oxidation. According to Sandegren (1947) in his work on barley proteins in brewing, proteins having sulfhydryl groups can be oxidized to higher molecular weight compounds by the following mechanism:

$$2R_1\text{–}SH + 2R_2\text{–}SH + O_2 \longrightarrow 2R_1\text{-}S\text{-}S\text{-}R_2 + 2H_2O$$

In addition, albumins can be oxidized to nucleoproteins with attendant change of the charge from positive to negative. The negatively charged oxidation products can then combine with unchanged positively charged proteins, thus increasing the molucular weight and causing mutual precipitation.

The net result of oxidation is to shift the equilibrium between the different fractions so carefully set up during brewing. The distribution of protein fractions at various stages during brewing, and four months after bottling, is shown in Table 116. Examining the values in the table, it

TABLE 116

PROTEIN DISTRIBUTION IN BEER AT VARIOUS STAGES

	Kettle Sample	After Fermentation	After Storage	After Pasteurization	After 4 Months
High molecular, per cent	0.1537	0.1452	0.0716	0.0860	0.1250
Medium molecular, per cent	0.1328	0.0959	0.0811	0.0858	0.1051
Low molecular, per cent	0.2066	0.1109	0.1965	0.1796	0.1180
Non-protein, per cent	0.031	0.027	0.300	0.028	0.029
Total protein, per cent	0.5241	0.3790	0.3792	0.3792	0.3800
High/total, per cent	29.31	38.31	18.88	22.66	33.00
Medium/total, per cent	25.34	25.30	21.38	22.67	27.65
Low/total, per cent	39.40	29.25	51.84	47.34	31.05
Non-protein/total, per cent	5.95	6.14	7.90	7.33	8.30

can be seen that the amount of protein in all fractions decreases during fermentation, accompanied by an increase in the ratio high/total and a decrease in the ratio low/total. This can be ascribed to the use of proteins, especially amino acids and other low molecular weight components, by the yeast. It will be noted that the total protein remains essentially constant once fermentation has been completed, but that the distribution in the different fractions changes markedly. The decrease in the high molecular fraction and in its ratio to the total during storage is a result of chillproofing. The chillproofs in common use today are essentially pro-

teolytic enzymes, added for the specific purpose of hydrolyzing the high molecular weight proteins, which are associated with tannins in complex compounds and tend to precipitate at low temperatures, to lower molecular weight compounds which do not precipitate. The progressive increase in the high molecular at the expense of the low molecular fraction after bottling is due to oxidation and the mechanisms described above. It may be mentioned that these changes are accelerated by pasteurization, oxidation being favored by the high temperature and by the dissolving of air from the head space in the bottle in the beer during heating, resulting in more intimate contact of the oxygen with the beer. As oxidation continues, it has a noticeable effect on the appearance and flavor of the beer. The brilliance decreases progressively and finally a definite haze, known as oxidation haze, is visible. This haze is the result of formation of high molecular weight protein complexes having colloidal dimensions. It is of a different nature from chill haze, as it does not disappear on warming. With the advent of oxidation haze the beer has a definite "oxidation flavor" noticeable to the average consumer.

The distribution of protein fractions at the time the beer is bottled can be used to estimate its shelf life. Thus, if the proportion of high molecular components is higher than usual, the time required to reach the level of visible haze will be less than when this proportion is low at the start. At present, the only test in general use to give an indication of the probable shelf life of beer is the ITT (indicator time test) developed by Gray and Stone (1939) of the Wallerstein Laboratories. This test measures the reducing power of beer, which increases as the proteins are oxidized. However, it is influenced by other factors in addition to the state of oxidation of the proteins. While it is quite reliable in following the progress of oxidation in a single beer, its use to compare one beer with another sometimes leads to false conclusions. For example, the presence of hydrogen peroxide in beer has long been known to have a detrimental effect on its stability and the presence of as little as 0.005 per cent has been known to cause haziness. The peroxide is formed from the reaction of molecular oxygen and auto-oxidizable substances such as catechol, ascorbic acid, isoascorbic acid and electron transfer systems, notably reduced flavin nucleotides. In the presence of peroxide, the ITT may show a zero or low value, even in the presence of haze and oxidation taste.

In view of the deleterious effects of oxidation, many attempts have been made to prolong the shelf life of beer by adding antioxidants. Gray and Stone (1939) have recommended the addition of ascorbic acid, and this has found rather wide application in the industry. However, according to Barton-Wright (1956), its use alone may be dangerous because in removing oxygen it is oxidized to dehydroascorbic acid, which is an

oxidizing agent for glutelins. He considers reductones prepared from sugars to be more efficient.

Another type of antioxidant has been suggested by the present author (Ohlmeyer 1957). This is the glucose oxidase-catalase system, which removes oxygen by an enzymatic reaction. It will be noted in Table 117 that a typical beer contains 0.001 per cent glucose. This amount, though very small, is enough to bind several times the amount of oxygen normally present. In this system the glucose oxidase catalyzes the oxidation of glucose to gluconic acid and hydrogen peroxide. The catalase then breaks the hydrogen peroxide down to water and oxygen, but only half of the original amount of oxygen taken up is released. The overall reaction is expressed by the equation:

$$2\text{ glucose} + O_2 \longrightarrow 2\text{ gluconic acid.}$$

The addition of proteolytic enzymes to beer, as is done in chillproofing, will also lengthen their shelf life and delay the appearance of oxidation haze as well as decrease chill haze. However, these enzymes must be

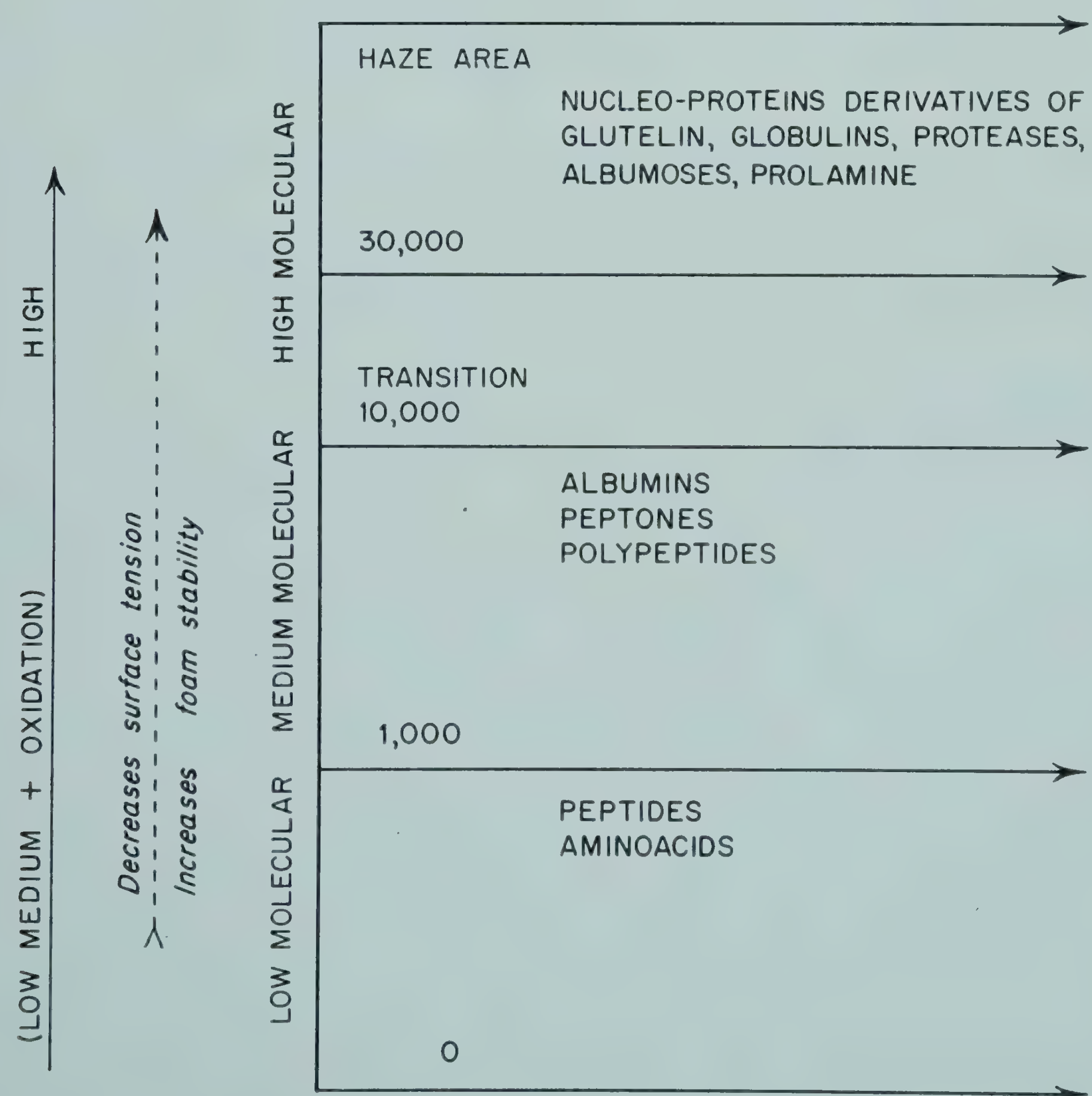


Fig. 139. Effect of Protein Distribution on Foam Stabilization

used with discretion, as too great a shift of the equilibrium toward low molecular fractions at the expense of the high and medium fractions will lead to foam instability and a poor head on the beer. This is caused by the changes in surface tension. All other things being equal, a higher and more stable foam is obtained with a low surface tension than with a high one. As the molecular weight of the proteins decreases, the surface tension of the beer increases and the foam is adversely affected. These relationships are illustrated in Fig. 139. In this figure the best compromise between optimum haze resistance and optimum foam stability is indicated by the shaded area. Thus, judicious use of proteolytic enzymes will result in an increase in the proportion of proteins in this optimum range without undue shifting of the equilibrium toward low molecular weight fractions.

NEW LABORATORY METHODS OF EXAMINING BEER

Methods for which literature references are not given will be briefly described below.

A. **Surface tension** was determined with a du Nuoy tensiometer.

B. **Surface activity** is calculated from the formula

$$\frac{72.75\text{–surface tension of beer (dynes) at } 68^\circ\text{F.}}{72.75}$$

The figure 72.75 represents the surface tension of water (dynes) at 68°F.

C. **Protein fractions** were determined by adaptations from the work of Luudin (as quoted by Pawlowski and Doemens 1932).

Total Soluble Protein

Place a porcelain chip and about 0.1 g. CuO-selenium metal powder mixture into an 800 ml. Kjeldahl flask. Pipette 25 ml. of decarbonated beer at 68°F. into the flask, add 28 to 30 ml. of the sulfuric acid digestion mixture. Digest until 30 minutes after all charring has disappeared. Cool, carefully add 200 ml. of distilled water. Transfer flask to distilling apparatus. Place 25 ml. of 0.1*N* sulfuric acid in a 250 ml. Erlenmeyer flask, add 2 drops methyl red indicator. Place on receiving end of distilling apparatus. Make sure tip of distilling apparatus is in the 0.1*N* acid solution. Cool condensers. Pour about 150 ml. of 30 per cent NaOH slowly down the side of the flask so as to form a layer. Add a few pieces of zinc. Attach tightly to the condenser. Shake flask, light Bunsen burner and distill until 100 to 150 ml. have been collected. Titrate with 0.1*N* sodium hydroxide until all the red color has disappeared. Record number of milliliters of 0.1*N* sodium hydroxide used.

Calculations.—

$$(\text{ml. } H_2SO_4 \times \text{Normality}) - (\text{ml. NaOH} \times \text{Normality}) \times .056 = \text{Nitrogen}/100 \text{ ml.}$$

$$\text{Nitrogen} \times 6.25 = \text{Protein}/100 \text{ ml.}$$

Permanently Soluble and Coagulable Protein

Weigh 100 gm. of decarbonated beer (at 68°F.) into a tared 500 ml. flat bottomed, round flask. Reflux for 3 hours. Cool. Restore to original weight with distilled water. Filter; do *not* wash. Pipette 25 ml. of filtrate into Kjeldahl flask. Proceed as with Total Soluble protein. (Distill into 15 ml. 0.1*N* sulfuric acid.)

Calculations.—

$$(\text{ml. } H_2SO_4 \times \text{Normality}) - (\text{ml. NaOH} \times \text{Normality}) \times .056 = \text{Nitrogen}/100 \text{ ml.}$$

$$\text{Nitrogen} \times 6.25 = \text{Protein}/100 \text{ ml.}$$

Coagulable protein = Total Soluble − Permanently Soluble

Formol Proteins: (Low Molecular Fraction)

Use 25 ml. of beer.

1. Adjust potentiometer at pH 4.0 with buffer solution.
2. Adjust 25 to 30 ml. formaldehyde to pH of 9.0 with 0.1 *N* sodium hydroxide.[1]

To start with, add about 1 ml. of the sodium hydroxide solution immediately, adding the remainder dropwise. Allow about one to two minutes of stirring to adjust pH.

3. Put sample of beer in place. Adjust pH to approximately 5 to 6.
4. Begin stirring sample. Add NaOH solution until pH is at 6.8.
5. Pipette 10 ml. of formaldehyde, add to solution stirring constantly.
6. Titrate with sodium hydroxide solution, noting initial reading on burette, until pH of 9.0 is reached. Note final reading.

Calculations.—

$$\text{ml. NaOH} \times \text{Normality} \times 0.056 = \text{Nitrogen}/100 \text{ ml.}$$

$$\text{Nitrogen} \times 6.25 = \text{Protein}/100 \text{ ml.}$$

Phosphomolybdate Precipitable Proteins (Medium Molecular Fraction)

Into a wide mouth 200 ml. volumetric flask place:

100 ml. beer
80 ml. distilled water
10 ml. 50 per cent sodium molybdate

[1] This solution should be used only on the day it is made up. It should not be made as a stock solution.

Put in water bath at 68° F. for 1 hour. Make up to mark. Add 10 ml. 50 per cent sulfuric acid; mix by inverting. Allow to stand over night. Filter. Use 50 ml. portions of filtrate for proteins. Proceed as for total soluble proteins. (Distill into 15 ml. of 0.1*N* sulfuric acid.)

Calculations.—

[(ml. H_2SO_4 × Normality)–(ml. NaOH × Normality)–correction for blank] × .0588 = non-precipitated Nitrogen

Total Soluble Nitrogen–non-precipitated Nitrogen = Phosphomolybdate precipitable nitrogen/100 ml.

Nitrogen × 6.25 = Protein/100 ml.

Tannin Precipitable Proteins (High Molecular Fraction)

Into a wide mouth 200 ml. volumetric flask place:

100 ml. beer
90 ml. distilled water
4 ml. fifty per cent sulfuric acid

Put in water bath for 1 hour at 68° F. Make up to mark. Add 10 ml. of 16 per cent Tannin; mix by inverting. Chill in an ice bath for at least one hour. Allow to stand over night in refrigerator. Filter. Use 50 ml. of filtrate. Proceed as with Total Soluble Protein. Distill into 15 ml. 0.1*N* sulfuric acid.

Calculations.—

[(ml. H_2SO_4 × Normality)–(ml. NaOH × Normality)–correction for blank] × 0.0588 = non-precipitated Nitrogen

Total Soluble Nitrogen–non-precipitated Nitrogen = Tannin precipitable Nitrogen/100 ml.

Nitrogen × 6.25 = Protein/100 ml.

Non-Protein Nitrogen

Phosphomolybdate–Tannin = Non-Protein Nitrogen

Blanks

Phosphomolybdate	*Tannin*
10 gm. Dextrose	10 gm. Dextrose
100 ml. water	100 ml. water
10 ml. Sodium Molybdate	4 ml. 50 per cent H_2SO_4
Make to mark	Make to mark
Precipitate with 10 ml. 50 per cent H_2SO_4	Precipitate with 10 ml. Tannin

Proceed as under Phosphomolybdate and Tannin.

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Samuel A. Matz

Manufacture of Breakfast Cereals

INTRODUCTION

History and Present Status of the Industry

Breakfast cereals may be conveniently divided into two major categories: (1) those cereals, such as oatmeal, which require cooking before they are served, and (2) fully cooked, ready-to-eat cereals such as corn flakes. The former class is probably about as old as civilization, since it is very likely that gruels and porridges made from crushed grains were among the first cereal foods of mankind. Prepared breakfast foods have a short and interesting history which has been well described by Carson (1957).

The original motivation for the development of precooked breakfast foods seems to have been the desire of some vegetarians to create additional variety for their diets. The Seventh Day Adventist Church, many members of which avoid the consumption of animal foods, was closely tied up with the early history of prepared breakfast foods. The close association of certain factions in this group with the Battle Creek Sanitarium and the cereal experimentation which they inspired at this institution, gave the city of Battle Creek a head start in the breakfast cereal industry. Today this city still houses the largest producers in the industry.

The first ready-to-eat breakfast cereal was probably "Granula," developed by Dr. James C. Jackson about 1863 at Dansville, New York. This health food was made by baking a coarse whole meal dough in thin sheets until it was hard and brittle, breaking and grinding the cake into small chunks, baking the chunks again, and grinding the resultant material into small granules.

The first breakfast food made by Dr. J. H. Kellogg of Battle Creek was named, by an interesting coincidence, "Granola." Kellogg made biscuits about one-half inch thick from a dough composed of wheat meal, oatmeal, and corn meal, and baked them until they were desiccated and beginning to turn brown. The hard biscuits were then ground and packaged. It was C. W. Post, the founder of Post Cereals, who first recognized that convenience and flavor were more forceful and more generally applicable selling points than were the healthfulness and vegetable origin of prepared breakfast cereals. Post became the first great merchandiser of these foods as a result of his grasp of this concept.

Since these early ventures in Battle Creek and elsewhere, prepared breakfast cereals have become recognized by persons in all walks of life as economical, convenient, and flavorful foods suitable for daily consumption by all age groups. The original granules and flakes have multipled into an array of forms, colors, and flavors which staggers the imagination. Additives and protein combinations have been developed to give the finished products a nutritional adequacy which is equalled by only a few foods. As a consequence of these changes, breakfast cereals have held or

TABLE 117

QUANTITY AND VALUE OF PRODUCTS OF THE UNITED STATES' BREAKFAST FOODS INDUSTRY[1]

Product	Total Shipments Including Interplant Transfers			
	1954		1947	
	Quantity[2]	Value[3]	Quantity[2]	Value[3]
Cereal breakfast goods, total	...	330,970	...	221,758
Ready-to-serve:				
Corn based foods	274,535	67,726	207,360	35,130
Wheat based foods	331,599	80,825	306,632	60,059
Foods based on other grains or on a combination of grains	320,025	97,465	199,155	52,945
To be cooked before serving:				
Wheat based foods (farina, etc.)	140,828	21,762	165,093	19,818
Rolled oats and oatmeal	449,785	46,726	504,657	42,919
Foods based on other grains or on a combination of grains	88,972	5,685	103,304	6,956
Other, or unidentified types	...	10,781	...	3,931

[1] Data from U. S. Bureau of the Census.
[2] In thousands of pounds.
[3] In thousands of dollars.

increased their levels of per capita consumption in recent years in spite of the overall decline in cereal food use. Their performance in this respect is superior to that of all other groups in this category with the exception of macaroni products.

The introduction of breakfast cereal factories into foreign countries has proceeded rather rapidly in the last two decades. These foods have had immediate acceptance in all areas where a good product has been offered. The future of the foreign market seems to be very promising.

THE TECHNOLOGY OF BREAKFAST CEREAL MANUFACTURE

Until fairly recently, breakfast cereal manufacturing was strictly an art. However, the larger producers are coming more and more to the conclusion that only by the application of scientific principles to their operations can they keep pace with their competitors in new product development and product control. In arriving at this conclusion, the breakfast cereal industry has proceeded at a considerably slower pace than some

of the other cereal industries as indicated by the relative dearth of publications in the field. Pressure to secure competitive advantages has probably not been great enough to force a faster advance. This situation now appears to be changing, with a consequently greater motivation to improve and enlarge research, product and process development, and control departments.

In the manufacture of uncooked breakfast cereals, there are two rather general processing steps. One of these is the reduction of particle size and the other is the elimination from the product of some of the fibrous substances found in the whole grain. The effect of these practices is to reduce cooking time and to improve the texture and perhaps the digestibility of the food. There is usually no attempt to alter materially the natural flavor of the grain by hydrolyzing starches or caramelizing sugars. However, it is true that the heat treatment applied to oatmeal changes the flavor somewhat. Recent advances in technology have resulted in cooking times being decreased to the point where addition of boiling water to the raw food will give a fully prepared product.

Ready-to-eat breakfast cereals, although they are extremely diverse in appearance, composition, and flavor, have at least two unifying processing principles. One of these is the creation of a crisp texture by drying the cooked product with its content of gelatinized starch to a moisture content of about 3 to 5 per cent, and the other is a flavor change which results from the dextrinization, gelatinization, and caramelization of the cereal starches and their degradation products.

In subsequent sections of this chapter, an attempt will be made to give the salient points of the most important processing techniques used in the breakfast cereal industry.

Processing of Uncooked Breakfast Cereals

Wheat Cereals.—The wheat cereal having the largest consumption is farina. This product is nothing more than the wheat middlings which are more fully described in the chapter on *Milling*. Middlings are chunks of endosperm free of bran and germ. When reduced in size, middlings become flour. In the manufacture of farina, it is necessary to use hard wheat as a raw material since soft wheat yields a product which becomes excessively pasty upon cooking. About 30 per cent of the wheat can be secured as farina by good milling techniques.

Particle size is thought to be a critical factor influencing consumer acceptance. The federal specification (Anon. 1952) for farina requires that: 100 per cent of the product pass through a U. S. Standard No. 20 woven-wire-cloth sieve; not more than 10.0 per cent pass through a No. 45 sieve; and not more than 3.0 per cent pass through a No. 100 sieve.

Vitamin and mineral enrichment is usually applied to farina. The federal specification quoted above establishes the following permissible ranges when enrichment is claimed: thiamin, 2.0 to 2.5 mg. per pound; riboflavin, 1.2 to 1.5 mg. per pound; and niacin or niacinamide, 16.0 to 20.0 mg. per pound. Vitamin D, calcium, and wheat germ are optional enriching ingredients, but, if they are included, minima must be met for the first two, and a maximum of eight per cent is established for the wheat germ. Vitamins are usually added in the dry state.

Disodium phosphate has been used (at about the 0.25 per cent level) to increase the speed at which farina cooks. Recently, an "instant" farina has come upon the market. This farina is ready-to-eat after about one minute of boiling time. Apparently, it is farina which has been treated with proteolytic enzymes. Originally, it is believed that bromelin was used in this process, but other enzymes may have been substituted in current production. The function of the proteolytic enzymes is said to be the opening up of microscopic pathways for water penetration in the granule.

Farina flavored with malt or with cocoa is marketed. Generally, these products are simple mixtures of the flavoring ingredient with the middlings.

Whole wheat meal, cracked wheat, flaked wheat, and farina with bran and germ are sold to a rather limited extent. The stability of these foods is limited by the tendency of the bran and germ oils to become rancid unless the product is specially processed.

Oat Cereals.—Gunderson and Brownlee (1938) gave a complete description of rolled oat processing. Methods have not changed much since that time.

Most oats for human consumption are marketed as rolled oats. Some demand also exists for ground oats and steel-cut groats. The initial step in the preparation of rolled oats is the roasting process. Thoroughly cleaned grains are heated to 212° F. for one hour. This roasting procedure reduces the moisture content to about six per cent and probably partially dextrinizes the starch. In addition, the hulls become fragile rather than tough, and are more easily removed during the subsequent processing.

After cooling, the roasted grains are separated according to size. The hulls are then removed by passing the kernels between two large circular milling stones mounted horizontally with the grinding surfaces separated by a short distance. The upper, or rotating, member of this pair of stones has a very slightly convex milling surface, while the lower stone, which is stationary, has a flat surface. Oats enter at the center of the upper stone, and are carried to the periphery by centrifugal motion. The dis-

tance between the rolls is everywhere more than the width of a de-hulled kernel, but is less than the length of the kernels. As the grains travel outward, the hulls are removed by the tearing and abrading action which they undergo. The grain with its hull removed is called a groat. The mixture of hulls, groats, and broken grains from the mill is screened and subjected to other procedures to separate the components. In some plants, hulling is achieved by impact methods, using devices such as the Entoleter.

The next step is flaking. Whole groats may be flaked, or they may be first cut into pieces by rotary granulators. The smaller the piece size, and the thinner the flake, the more quickly the product can be cooked. For example, the so-called quick oats, which are flakes made from a particle about $^1/_3$ to $^1/_4$ the size of the whole groat, cook in about five minutes, while flaked whole groats, "regular oats," are thoroughly cooked after 10 to 15 minutes boiling. On the other hand, the quicker cooking oats do not stand up as well under prolonged heating such as they might encounter on the steam table of a cafeteria. Regular oats will maintain a satisfactory texture for about three hours on the steam table, while the quick oats become undesirable after about one hour under the same conditions. By making a thicker flake from the whole groat, oats withstanding six hours of heating can be obtained. Steel-cut oats (not flaked) are even more resistant to overcooking.

Corn Cereals.—Corn meal in the form of mush and boiled hominy grits are sometimes used as hot breakfast cereals. The preparation of these products is described in the chapter on *Milling.*

Rice Cereals.—Whole milled rice is occasionally cooked to give a breakfast cereal. Full details on this product are given in Chapter 16 on *Rice Processing.* A product recently introduced consists of milled rice ground into particles about the size of those which make up farina. Because of the particle size, the product is instant cooking, that is, it does not require additional heating after the addition of boiling water to the rice. A short period of standing after the addition of water is necessary, of course.

FLAKES

General Considerations

Flaking is a relatively simple process, consisting in its most elemental form of cooking fragments of cereal grains (or sometimes whole grains), flattening the soft particles between rollers, and toasting the resultant flake at high temperatures. Apparently the first commercial production of such a food occurred around the turn of the century when J. H. Kellogg and W. H. Kellogg made whole wheat flakes in a barn behind the Battle

Creek Sanitarium. Many complications have been introduced into the process since that time in attempts to improve the flavor and the efficiency of operations, and to increase the uniformity of flake size and appearance which is so desirable to the manufacturer and perhaps even to the consumer.

In the basic processing steps, the raw material undergoes the following changes: (1) the starch is gelatinized and probably slightly hydrolyzed; (2) the particle undergoes a browning reaction due probably to inter-

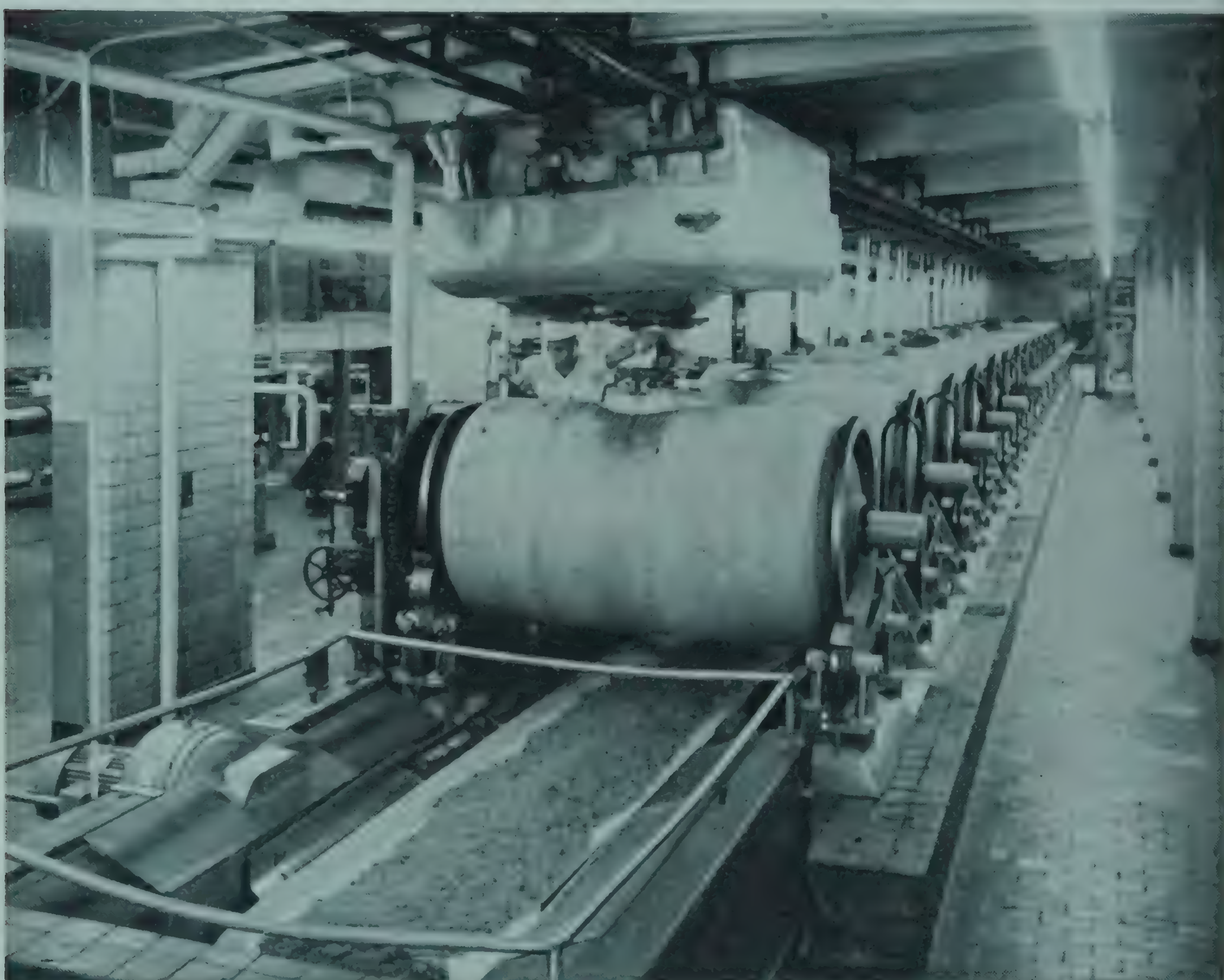


Fig. 140. Retorts for Cooking Flake Ingredients

action of proteins and sugars; (3) enzymic reactions are stopped, rendering the final product more stable; (4) dextrinization and caramelization of the sugars occur as a result of the high temperatures in the roasting oven; and (5) the flake becomes crisp as a result of the reduction of its moisture content to a very low level.

Flakes owe their popularity with consumers to their crisp but friable texture, to their sweet but rather bland flavor, and to the ease with which a portion may be readied for consumption.

In the subsequent paragraphs of this section, a fairly straight-forward

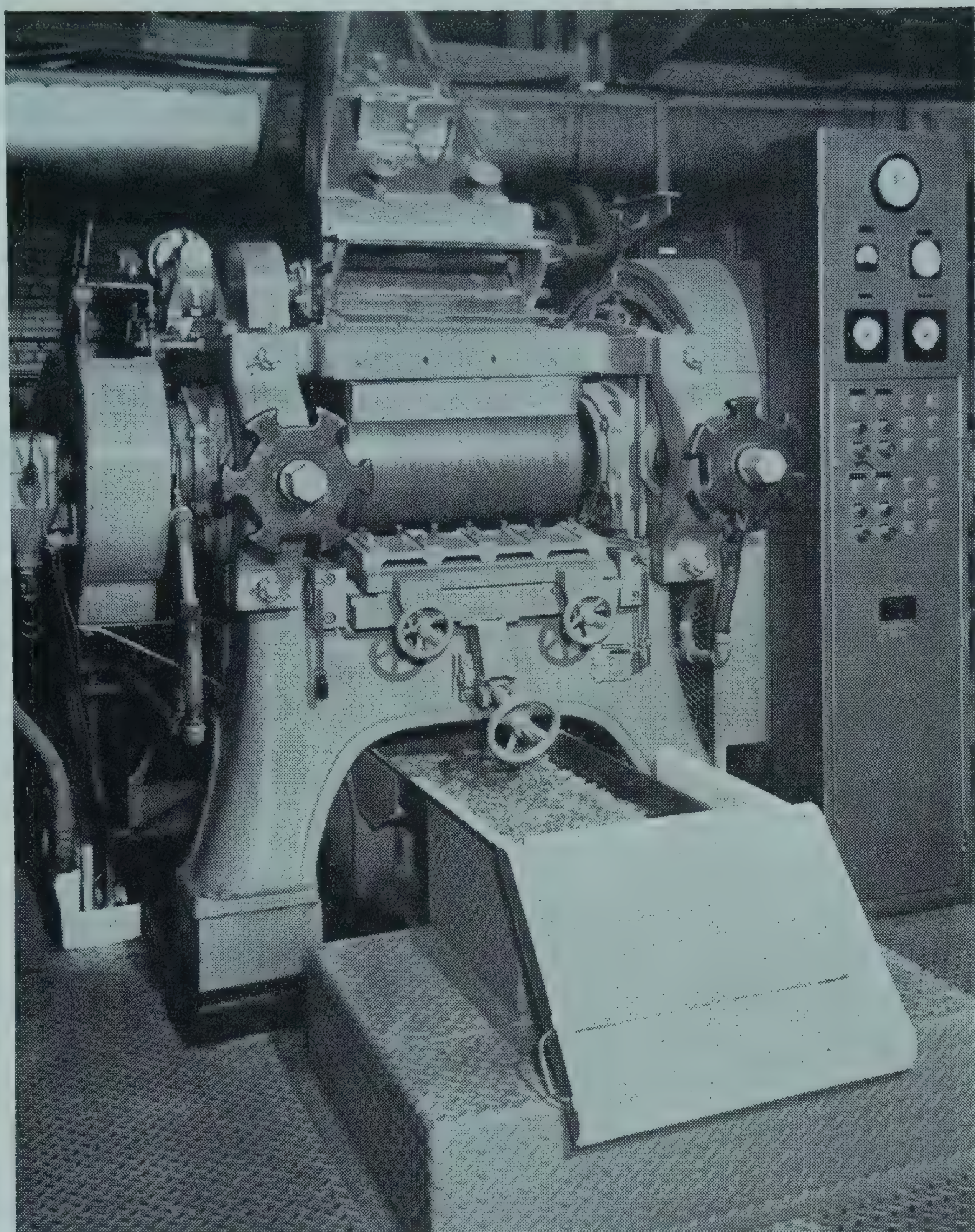


FIG. 141. A SET OF FLAKING ROLLS

corn flake operation will be described first, followed by a discussion of a wheat flake production method which is considerably more complex. Bran flakes, 40 per cent bran flakes, and rice flakes are also marketed and are produced by quite similar methods.

Corn Flake Production

Hybrid yellow corn is usually used, although white corn provides an equally satisfactory raw material. The corn is broken (milled) so as to yield a No. 4 to No. 5 grit, free of germ and bran. These large pieces represent about one-half of a corn kernel, and they retain their identity throughout the processing, each particle eventually emerging as a corn flake. Into a cylindrical pressure cooker is placed about 1700 lbs. of the grits and 36 gallons of a flavoring syrup consisting of sugar, malt (non-

diastatic), salt, and water. Occasionally niacin is also added at this point. During the cooking period the charge accumulates additional water from the steam introduced into the retort, rising to about 33 per cent moisture.

Cooking is done in the slowly rotating retort at 15 to 23 (typically 18) lbs. per sq. in. steam pressure for 1 to 2 hours. Different lots of corn may vary considerably in the duration of the cooking time required. The end point can be judged by examining a small sample of the charge which is blown out through a gate valve for this purpose. A uniform translucency in the kernels indicates an adequate cook. At this time, the pressure is reduced to the atmospheric level, the retort is opened, and the contents are dumped out onto a moving belt.

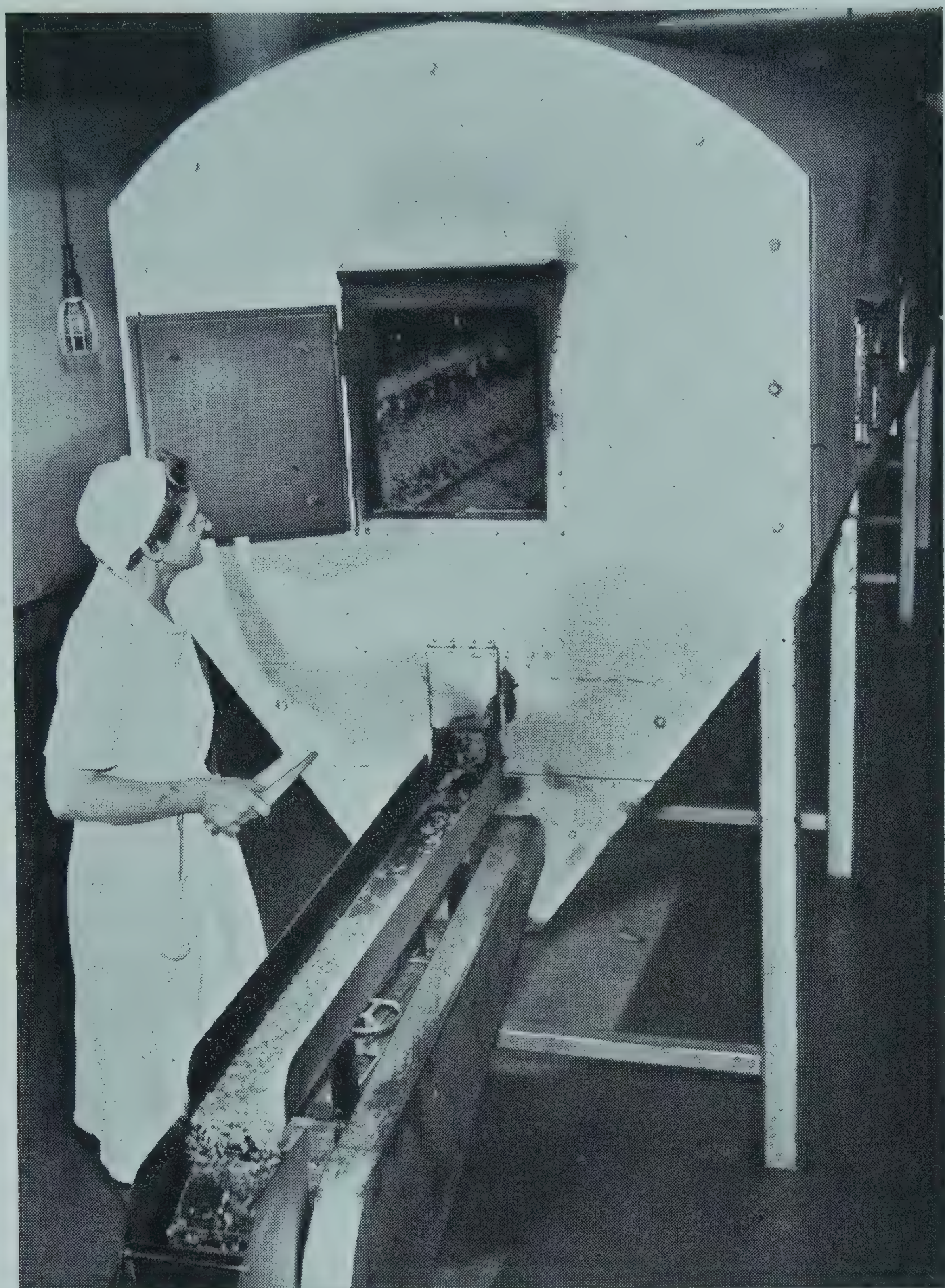
After the lumps from the cooker are broken down to individual particles by a revolving reel, they are distributed to a set of driers. The latter devices are essentially large tubes or tanks extending vertically for several stories. The wet kernels enter the top and are dried by a countercurrent of hot (150°F.) air as they travel to the bottom. Another type of drying set-up consists of horizontal rotating cylinders having numerous steam-heated pipes passing longitudinally through them. Louver driers may also be used.

The dried particles now contain 19 to 23 per cent moisture, but this water is unevenly distributed, so the material is transferred to tempering bins for several hours (as many as 24) so that the moisture may equilibrate. After tempering, the hard, dark brown grits are ready for flaking.

The flaking rolls are steel cylinders weighing over a ton each, and revolving at a speed of about 180 to 200 revolutions per minute. Hydraulic controls maintain a pressure of over 40 tons at the point of contact of the rolls. The rolls are cooled by internal circulation of water. The cooked dried grits are pressed into thin flakes as they pass through the rolls. The product is still rather flexible at this time, lacking the desired crispness and preferred flavor of the finished corn flake.

From the rolls, the flakes pass directly to the rotating toasting ovens, which are usually gas fired. The moist flake is tumbled through the perforated drums and passes within a few inches of the gas flames. Treatment may be 50 seconds at 575°F., or two to three minutes at 550°F. In addition to being thoroughly dehydrated by the process, the flakes are toasted and blistered. They emerge from the oven with less than three per cent moisture.

From the ovens, the flakes are carried by belts to expansion bins where they are permitted to cool to room temperature. *En route*, the product is cooled by circulating air and is usually treated with a spray of a solution of thiamin and perhaps other B vitamins.



Courtesy of Kelloggs

FIG. 142. A TOASTING OVEN FOR WHEAT FLAKES

The Manufacture of Wheat Flakes

Plump kernels of wheat are used as the raw material for wheat flakes. After cleaning and classifying according to size, the wheat is tempered with added moisture in steel bins of small diameter at approximately 80°F. for 24 hours. The wheat may be transferred one or more times during this period if such a procedure is necessary in order to keep the temperature within reasonable limits. After tempering, the wheat is steamed at atmospheric pressure until it reaches about 203°F. and 21 per cent moisture.

The steamed wheat is "bumped" between smooth steel rollers set con-

siderably farther apart than are flaking rolls. This treatment flattens the grain slightly and ruptures the bran coat in several places making the kernel more permeable to the moisture added during the cooking step. The flattened kernels are transferred to the pressure cookers, which are similar to those used for corn flakes, and the other ingredients are added. These ingredients include sugars, salt, malt, and sometimes a coloring substance such as caramel.

The retort contents are cooked at 20 lbs. per sq. in. steam pressure for 90 minutes while the vessel rotates slowly. After cooking, the grains are soft, translucent, and brown. They contain about 45 to 50 per cent moisture. The starch has, of course, completely gelatinized. Rotation of the opened retort dumps the contents onto a moving belt which transfers the cooked mass to a chute leading to a "Wiggler."

The Wiggler consists of a horizontal perforated disc, through which warm air is blown in an upward direction, and a rotating arm carrying vertically-oriented inflexible fingers around its upper surface. The clumps of slightly adherent grain are dropped onto the center of the perforated disc and are broken up and the individual grains moved to the outer edge ot the disc by the moving fingers.

The individual grains fall from the edge of the disc and are transferred pneumatically to a horizontal rotating cylinder fitted with internal louvers. In this drier, air at 250 to 300° F. is passed over the grain, reducing it to 28 to 31 per cent moisture. Holding bins are used to store the material until it can be transferred to the presses.

At this point, the grains are still intact and are rather tough and chewy in texture. Subsequent processing is designed to secure the required crispness. First, the wheat pieces travel through a drier. This might be a Proctor and Schwarz drier composed of three sections, the first at 280°F., the second at 290° F., and the third unheated. Rate of movement of the material is adjusted to yield a product of about 21 per cent moisture. A spray of B-complex vitamins is applied at this stage.

Screw conveyors or drag chain conveyors transport the partially dried pellets to the flaking rolls. Just before falling into the flaking rolls, the pellets are heated, to about 180° to 190° F. and they become plasticized. The large steel flaking rolls are practically identical with those used for making corn flakes. The pressure applied to the pellets increases their diameter several times and decreases their thickness proportionately.

When they leave the rolls, the flakes are at 10 to 15 per cent moisture content and are still slightly flexible. To obtain the desired crispness, they are toasted and dehydrated to less than three per cent moisture content in a drier with a perforated travelling metal belt. Temperature in the oven may be divided into four regions; for example, heated sections

at 310°, 300° and 280°F., and an unheated section to cool partially the product. The decreasing temperature is said to promote the development of the desirable curling and blistering.

SHREDS

General Considerations

By far the most popular representative of this class is the shredded wheat biscuit manufactured by several United States firms. Loose wheat shreds are manufactured by one or two concerns, and a combination corn and soya product in the shredded form is being marketed. Processing of all of these foods is similar until the biscuiting step is reached, so the present discussion will be devoted to the more inclusive procedure: the manufacture of shredded wheat biscuits.

Shredded Wheat Biscuits

This product differs from most other prepared breakfast cereals in that it is made from whole grain without the addition of any flavor and without the removal of the germ or bran. Cooking may be done at atmospheric pressure, in boiling water. After an hour or more of cooking, the moisture content of the wheat has reached 50 to 60 per cent and the kernels are very soft. Some preliminary drying in louver ovens may be done at this time, but the whole wheat is not brought much below 45 to 50 per cent moisture. The cooked and partially dried wheat is transferred to stainless steel bins and tempered for many hours before it goes to the shredding rolls.

The shredding rolls are from 6 to 8 inches in diameter and as wide as the finished biscuit is to be and thus are much smaller than flaking rolls. On one of the pair of rolls is a series of about 20 shallow corrugations running around the periphery. In cross section, these corrugations may be rectangular, triangular, or a combination of these shapes. The other roll of the pair is smooth. Soft cooked wheat is drawn between these rollers as they rotate, and issues as continuous strands of dough.

Biscuits are built up by layering strands on a moving belt which passes under sets of rolls working in tandem. Ten to 18 rolls may be used for circular biscuits, while 22 rolls is a common number for rectangular biscuits. In the latter case, layered strands are separated into biscuits by passing them between two blunt "knives" which fuse a thin line of the dough into a solid mass at regular intervals.

Circular biscuits are formed quite differently. One end of the layered strands of whole wheat dough is caught up by a smooth roll which rotates just above the belt. This roll turns the layer of strands back upon itself,

and the forward motion of the belt, combined with the reverse and upward motion of the cylinder surface, causes the layer to roll up into a circular biscuit. As the biscuit reaches the proper size, a knife chops down on the belt, severing the strands so that the formed biscuit is released. Automatic controls vary the speed of the belt as the diameter of the biscuit increases. The completed disc falls into a cup from which it is transferred to a belt leading to the ovens.

Since the biscuits are formed from dough of relatively high moisture content, they are quite tender, and must be handled very carefully to prevent distortion. In practice, this means that the transfer steps must proceed more slowly than is necessary with flakes or puffed products.

The wet biscuits are placed on a metal belt moving through a high temperature gas-fired oven. After 10 to 15 minutes, the outside of the product is dry and toasted while the interior is still wet. Then the biscuits are transferred to another hot air oven (or to a different section of the same oven) where they are dried at 250°F. for 30 to 60 minutes through time depending upon the size and the air flow. Finished moisture content is about eleven per cent. The combination of heat treatments causes the biscuit to assume the familiar oval cross-section.

Hale and Carpenter (1956) described the preparation of a biscuit having a lattice-like network of shreds. Their product may be puffed and therefore resembles not only shredded wheat biscuits, but also the product patented by Huber (1955) as described in the *Puffing* section of this Chapter (p. 560).

The flavor of shredded wheat differs markedly from that of whole flakes because the latter include added condiments and are subjected to much more heat in both the cooking and the toasting step. The more rigorous heat treatment applied to flakes results in considerably more caramelization in the finished product.

Rancid odors tend to accumulate if shredded wheat is stored in sealed containers. For this reason, the product is sold in "breather" boxes without outer or inner linings. When so packaged, the product is just as stable to storage deterioration as any other prepared cereal except that moisture absorption may occur in atmospheres of high relative humidity with a consequent loss of crispness.

CEREAL GRANULES

The only product of this type being marketed on a nationwide basis is the Grape-Nuts made by Post Cereals Division of General Foods Corp. It is manufactured by a method quite different from that applied to any other breakfast cereal. In essence, this food is the toasted fragment of

a loaf of bread—albeit an unusual type of bread. It bears a strong resemblance to some of the earliest types of precooked cereals.

The initial step in the manufacture of cereal granules is the preparation of a stiff dough from wheat, malted barley flour, salt, dry yeast, and water. A dough weight of 1600 lbs. is a common size. After mixing, the dough is dumped into troughs and stored at 80°F. and 80 per cent relative humidity for $4^1/_2$ to 5 hours. During this stage, much hydrolysis of the starch to sugars occurs by virtue of the action of the malt enzymes and some leavening takes place as a result of the yeast fermentation.

Courtesy of Post Cereals

FIG. 143. REMOVING GRAPE-NUTS LOAVES FROM THE OVEN

At the end of the fermentation period, the dough is formed into loaves and transferred to the ovens without the intervention of a proofing period. The loaves are baked for two hours at 400°F. and then depanned (Fig. 143).

The baked loaves are fragmented by shredding knives, or saws, and the pieces transferred to the secondary ovens after passing through a sizing step which removes fines. After two or more hours of baking at

FIG. 144. FRAGMENTED GRAPE-NUTS LOAVES LEAVING THE TOASTING OVEN

about 250°F., the pieces are broken up into small granules which are carefully sized before packaging. Fines from each stage of the operation are used in subsequent doughs.

PUFFED CEREALS

General Considerations

Puffing processes may be conveniently divided into two types: (1) atmospheric pressure procedures which rely upon the sudden application of heat to obtain the necessary rapid vaporization of water; and (2) pressure-drop processes which involve suddenly transferring superheated, moist particles into a space at lower pressure. In the latter case, the pressure drop may be achieved by releasing the seal on a vessel containing a product which has been equilibrated with high temperature steam, or it may be secured by transferring the hot material from the atmosphere into an evacuated chamber. The former process is much more widely used.

The puffing phenomenon results from the sudden expansion of water vapor (steam) in the interstices of the granule. The particle is fixed in its expanded state by the dehydration resulting from the rapid diffusion of the water vapor out of it. Gun-puffing may result in an increase of apparent volume (bulk density decrease) of eightfold to sixteenfold for

wheat and sixfold to eightfold for rice. Oven puffing causes a lesser increase, about threefold to fourfold for rice.

Puffed products must be maintained at about three per cent moisture (or less) in order to have the desired crispness. Even at five per cent moisture a definite toughness becomes evident (Carlin 1956). These levels are more critical and harder to maintain in foods which have been gun-puffed.

Oven-Puffed Rice

This product is prepared from whole kernels of domestic short-grain milled rice. Frequently the rice is parboiled and pearled. A batch of 1400 lbs. of rice is weighed into cookers such as are used in the preparation of corn or wheat flakes. About $53^1/_2$ gallons of sugar syrup with salt are added, and the mixture is cooked for 5 hours under 15 lbs. steam pressure. Sometimes non-diastatic malt syrup and enriching ingredients are added before cooking.

The lumps of cooked rice coming from the retorts are broken up and dried to approximately 25 to 30 per cent moisture content in rotating louver driers. At this point, the moisture is allowed to distribute uniformly in the grain mass by storing the partially dried product in stainless steel bins for about 15 hours. Lumps form during the tempering process, and must be broken up before the rice is sent to the flaking rolls.

After the individual kernels are separated and again dried so that a moisture content of 18 to 20 per cent is reached, they are passed under a radiant heater which brings the external layers of the rice to a temperature of about 180°F. The outside layers of the kernel are plasticized by the heat so they do not split when the grain is run through the flaking rolls.

The rolls used in preparation of oven-puffed rice are set relatively far apart so that the tremendous compression effect necessary in corn flakes manufacture is not achieved. In fact, the rolls contact only the central part of the rice kernel. The "bumped" grains are again tempered, this time for about 24 hours.

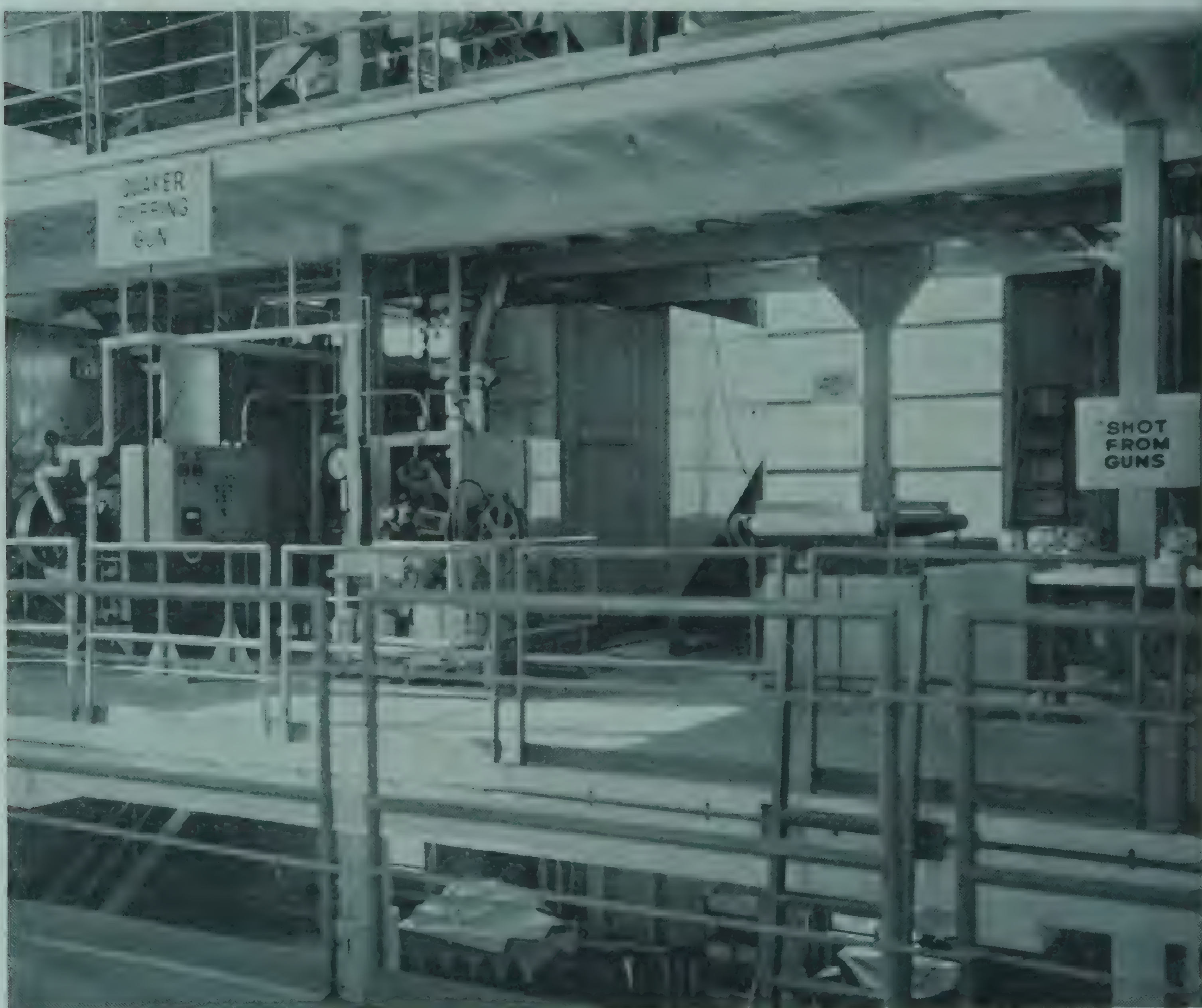
To secure the puffed effect, the cooled and tempered rice is passed through toasting ovens at 450° to 575°F. Transit time is about 30 to 45 seconds.

A cereal called "Special K," manufactured by the Kellogg Co., is basically a rice kernel which is cooked, then coated while in a moistened condition with wheat gluten, wheat germ meal, dried skim milk, debittered brewers' yeast and other nutritional adjuncts. Finally the material is oven-puffed. A more complete description of the product has been given by Thompson and Raymer (1958).

Gun-Puffed Products

The manufacture of a composite cereal by the gun-puffing method will be described since it includes several concepts not previously treated in this chapter.

Corn cones, oat flour, and a flavor pre-mix consisting of sugar, coloring substances, flavoring compounds, etc., are combined in a screw conveyor with interrupted flights. The homogenous mixture is dumped through a rotary valve into a continuous steam-jacketed cooker. Water is added



Courtesy of Quaker Oats Co.

Fig. 145. Pilot Plant Semi-Continuous Puffing Gun Installation

by a metering device so that the product going to the extruders is at 38 to 40 per cent moisture content.

Auger-induced pressure extrudes strands of cooked dough around the periphery of a circular die. A knife travelling over the die surface cuts the strands into short pellets. The pellets may be solid or have a hollow center. The pellets go to a tumbling cooker which reduces the surface moisture and prevents the occurrence of agglomeration. The product is

Courtesy of Quaker Oats Co.

FIG. 146. DOUGH PIECES EXPLODING FROM AN EXPERIMENTAL PUFFING GUN

piled about three inches deep on the metal belt of a Proctor and Schwarz oven.

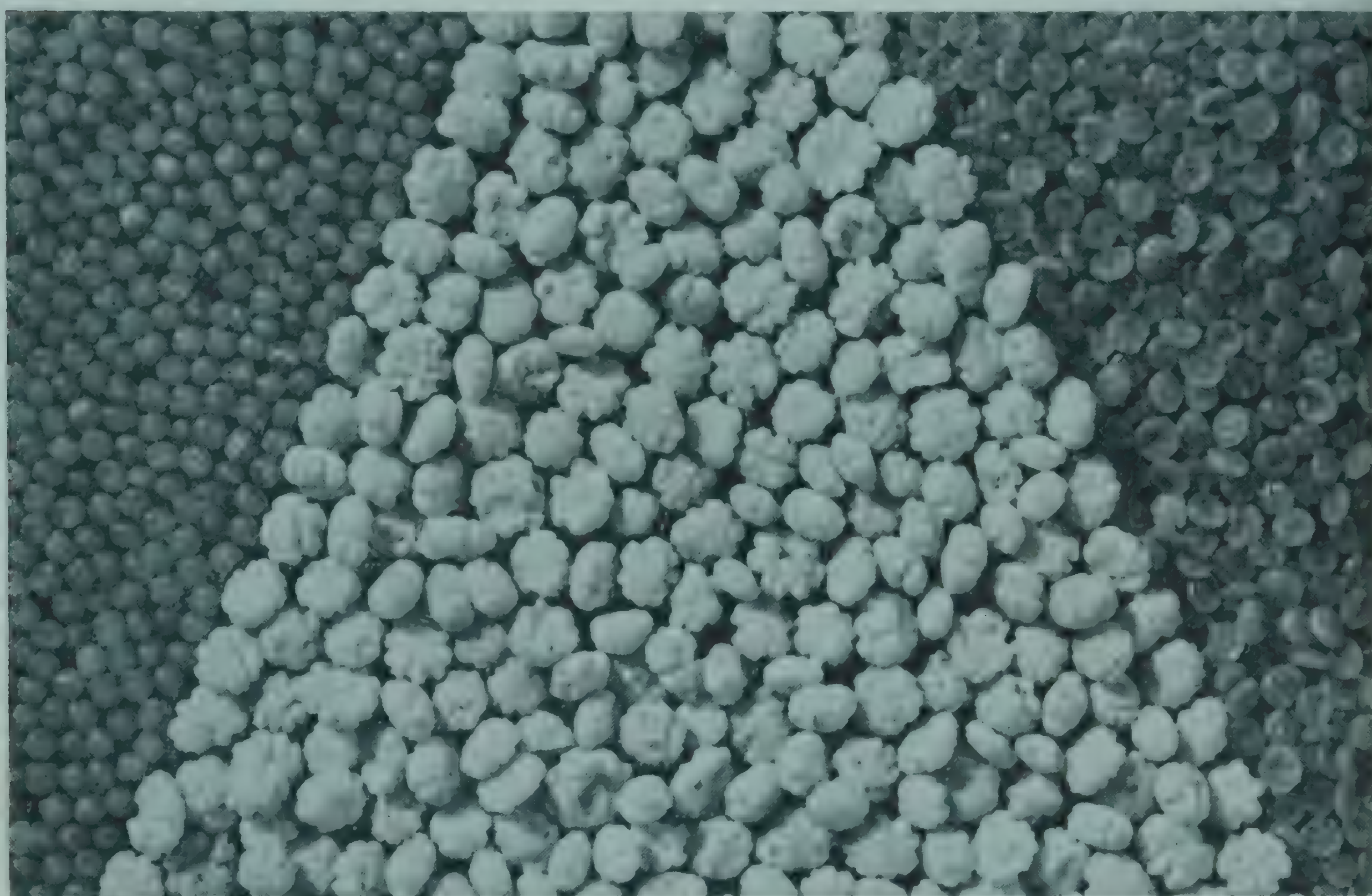
Solid pellets at 15 to 16 per cent moisture content may be bumped between rolls to make a disc-shaped particle with serrated edges.

The guns, so-called, are pressure vessels about six inches in diameter and 30 inches long. They are provided with a steam inlet, a bleed-off valve, and a means for heating the gun—usually by a gas flame. A charge of pellets at 11 to 12 per cent moisture content is dropped into the open end of the gun from a gravity chute leading from the storage bins on the floor above. The end of the gun is sealed by a trip-valve. All valves are closed, sealing the gun. If the gun is heated by gas flames, it is slowly rotated while the temperature, and consequently the pressure, is slowly built up. The temperature may reach 500° to 800°F., and the pressure at the end point may be 100 to 200 lb. per sq. in. This process may take 5 to 7 minutes.

When the pressure reaches the necessary level, the end of the gun is suddenly opened by a trigger mechanism. The contents explode (Fig. 146), into a cage or bin provided with a floor opening leading to a conveyor belt. The material is then visually inspected for color and agglomeration and sent to the packing line.

There can be almost endless variations on the preceding method. Cocoa can be added to the dough to make a chocolate flavored confection. Products may be made of any color for which there is a suitable edible dye. Shapes can be varied within a wide range. Raw materials may be almost any combination of cereals.

Some composite-dough, gun-puffed cereals are the trade-marked Kix, Coco-Puffs, Jets, Trix, Cheerios, etc.



Courtesy of General Mills

FIG. 147. PRODUCT AT VARIOUS STEPS IN THE PUFFING OPERATION

Left—extruded pellets of gelatinized dough; right—pellets which have been flattened between rolls; center—the puffed dough pieces.

Wheat and rice kernels can be gun-puffed. Usually durum or a hard wheat is used as the raw material for the puffed wheat, and it is often pearled before puffing to reduce the amount of bran present on the finished product. This bran becomes loosened by the puffing process, and if an excessive amount is present, it can form an unsightly deposit in the bottom of the package.

Alternate Puffing Methods

Processes dependent upon contact of dough pieces with very hot embossed cylinders are in current use. Huber (1955) describes such a method in which roll temperatures of 350° to 800°F. are used. Very likely, in practice, temperatures in the upper half of this range would be

Courtesy of Post Cereals

FIG. 148. THE COATING REEL

A rotating drum in which sugar syrup is applied to toasted flakes.

employed. The rolls may be heated by radiant (infrared) heat or by the circulation of high temperature fluid media inside the cylinder. In Huber's process, the dough has a moisture content of 8 to 18 per cent going into the rolls and 6 to 7 per cent after puffing. The dough may be preheated to temperatures below boiling: in this case lower roll temperatures are practicable.

Gates (1958) described a cereal puffing method which is somewhat analogous to gun-puffing except that the grain is steam-treated under less pressure than usual and is puffed by passing into a chamber having a considerable negative pressure with respect to the atmosphere. Gates' method also differs from gun-puffing in being continuous. It has been used to make a quick-cooking rice, but apparently there are no prepared breakfast cereals being made by this method.

Sugar-Coated Products

Spherical or disc-shaped products such as puffed wheat and rice can be coated by a method very similar to the pan-coating technique used in confectionery manufacture. The requisite apparatus somewhat resembles a cement mixer in having an open bowl rotating about an axis inclined to the horizontal. The very dry cereal particles are placed in the bowl,

and, as it rotates, a molten (250° F.) sugar syrup is slowly dripped upon the mass. The tumbling action of the particles results in each of them remaining separate and being uniformly coated with a thin glaze of sugar which hardens upon cooling.

Some details of the syrup preparation and its storage have been given by Massman and Rivers (1955). Other authorities have suggested a syrup formula of about 86 per cent sucrose, 13 per cent corn syrup, and one per cent salt. Sometimes 0.01 to 0.05 per cent sodium acetate may be added to prevent crystallization of the coating. From 25 to 60 per cent of the weight of the finished product is due to the glaze.

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SECTION III

Functional and Storage Characteristics of Cereal Products

Majel M. MacMasters
and Ivan A. Wolff

Characteristics of Cereal Starches

The starch content of cereal grains varies somewhat with growing conditions and with the specific grain under consideration, but it is roughly about 70 per cent. It is evident that in any food or feed produced from a cereal grain, starch is a constituent that must be given primary consideration. From a nutritional standpoint, of course, the actual source of the starch is insignificant.

Starch may have quite a different function from that of caloric value, however, through the role that it can play in modifying the characteristics of foods. Examples of cases in which starch properties are deliberately used in foods include the thickening of gravies and pie fillings, the molding of puddings, the stabilizing of salad dressings and ice cream, and the making of gum drops and other gum confections.

The powdery nature of dry starch, which permits its molding into tablets, and its property of quickly wetting without the development of adhesiveness or loss of granular structure, makes starch a good carrier for drugs and for adjuncts to feeds.

Proper choice of starch for a specific use must be based on knowledge of the physical and chemical characteristics which will give the desired result. Consideration and comparison of the characteristics of both unmodified and modified cereal starches are of importance to food and feed manufacturers in choosing the proper starch for each use.

UNMODIFIED STARCHES

Starch occurs in plants in the form of granules, the size and shape of which depend on the plant species. Granules from different plants vary not only in appearance but also, to a minor degree, in chemical composition.

Granule Size and Microscopic Appearance

Starch granules are roughly spherical or ovoid in shape. They appear, microscopically, to be composed of concentric layers of material arranged

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around a dark spot known as the hilum. The layers, or lamellae, are often indistinct or invisible in cereal starches, but can be demonstrated by swelling the granules in alkaline reagents.

When a dry starch granule is crushed without shearing, it breaks into wedge-shaped fragments along radial lines. Radial organization is also clearly indicated by the interference cross, centered at the hilum, which the granule shows when viewed between crossed polarizer and analyzer. The starch granule, therefore, is considered to be a typical spherocrystal.

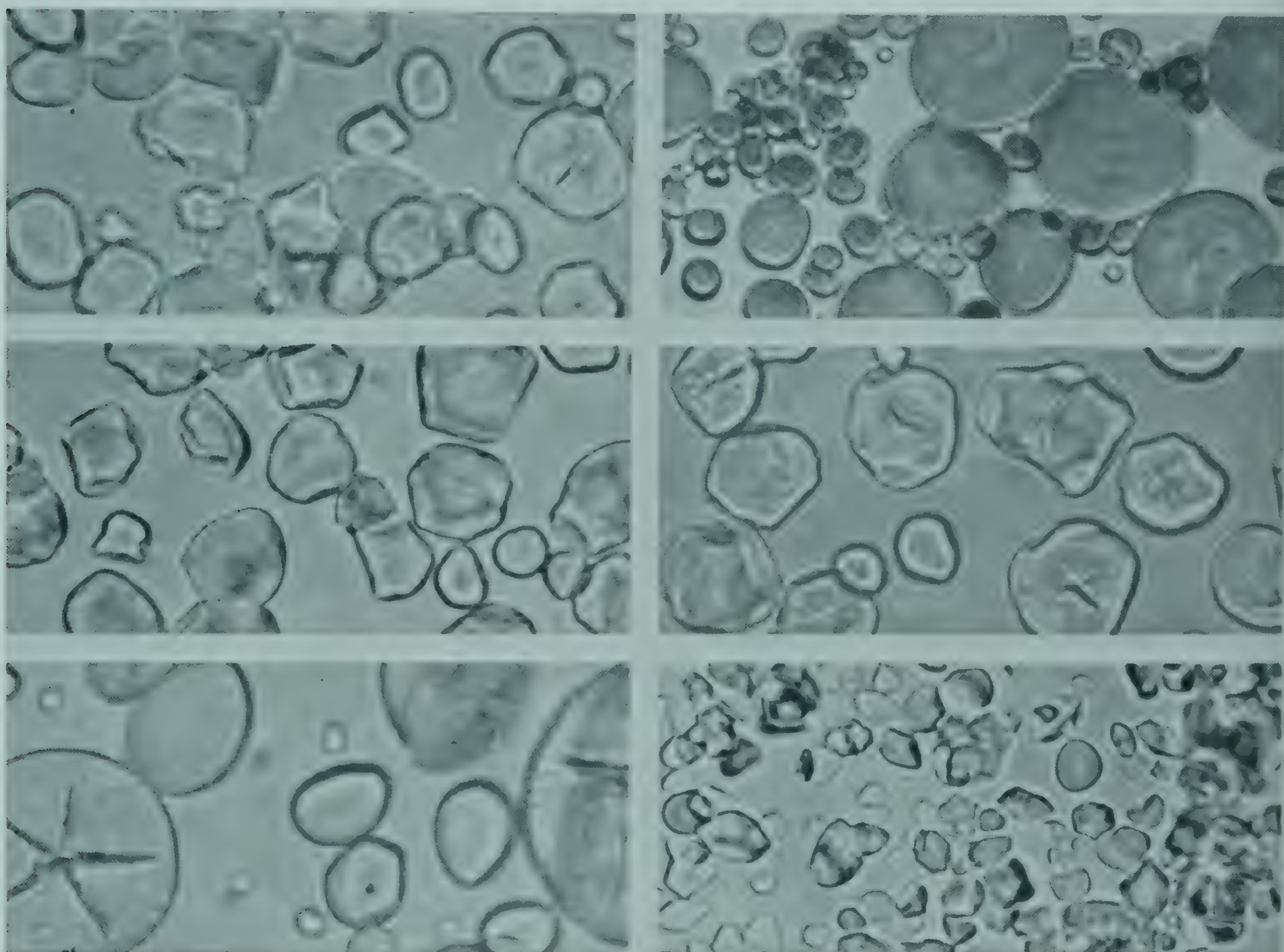


FIG. 149. UNGELATINIZED STARCH GRANULES

Upper: Left, corn; right, wheat.
Center: Left, waxy corn; right, grain sorghum.
Lower: Left, rye; right, oats.
Magnification 500×

The hilum is an open area found at the center of spherical granules and near one end in ovoid granules. It sometimes has long branches. Some workers have considered the hilum to be an area of reduced pressure or vacuum, but the permeability characteristics of the granule are in opposition to this view. In root starches that have never been dried, the hilum is observed to be full of water. Similar observations cannot be made on cereal starches because they dry in the kernel. If a cereal starch granule is placed on a microscope slide and surrounded with glycerol,

the slow movement of the viscous glycerol into the granule can easily be watched. When the glycerol reaches the edge of the hilum, the latter is clearly seen to contain an air bubble. As the glycerol displaces or dissolves the air, the bubble slowly disappears and the hilum is progressively filled with liquid. The air bubble at the hilum is also easily demonstrated by chemical gelatinization of the granule. Movement of the bubble can be followed microscopically until it finally dissolves in the liquid. If the granule is saturated with water before treatment, no bubble appears.

Cornstarch.—Cornstarch granules are spherical to polyhedral in shape, with a diameter of from 2 to about 30 microns. Spherical granules occur in flour corn and in the floury inner endosperm of other types of corn. In the outer horny endosperm, which comprises most of the endosperm of flint and popcorns and much of that of many dent varieties, the granules are so tightly packed that they are forced into polygonal shapes. The lamellae of cornstarch granules are indistinct or invisible. The hilum is roughly spherical or slightly branched, giving it a stellate appearance. The granules are strongly birefringent.

Waxy cornstarch granules are much like those of ordinary cornstarch in appearance and size, except that the maximum diameter of the waxy cornstarch granules is often a few microns larger. Waxy starch granules are best distinguished by staining with iodine which gives them a reddish-brown color in contrast to the blue coloration shown by ordinary starch granules.

Starch granules from high amylose corn may vary in size and shape. They are often of considerably smaller average and maximum size than ordinary cornstarch granules and some may be of Y, T, or L shape, while others are spherical (Deatherage *et al.* 1954). High-amylose starch cannot be distinguished microscopically from ordinary starch by coloration with iodine.

Grain Sorghum Starch.—Granules of grain sorghum starch are almost indistinguishable from those of corn. The upper limit of diameter is about 35 microns, however, and sorghum starch appears to have more large granules than are commonly found in cornstarch.

Waxy sorghum starch granules are closely similar to those of ordinary sorghum starch, but usually the maximum diameter is a few microns greater for the waxy starch granules. Their reddish-brown coloration with iodine distinguishes the waxy starch granules.

Wheat Starch.—Wheat starch is composed of two types of granules. The smaller granules are spherical while the larger ones are lens-shaped. There is no sharp correlation between size and shape. Lamellae may be fairly clear, indistinct, or invisible. The hilum is indistinct and roughly spherical in the small granules, plate-like in the large granules, i.e.,

elongated along the long radii of the granules. The long diameter of the granule may be as great as 38 microns. Wheat starch granules are only moderately birefringent.

Barley Starch.—Barley starch has much the appearance of wheat starch except that the granule diameter may be as great as 48 microns. There are generally fewer small granules in barley starch than in wheat starch.

Waxy barley starch granules appear much the same as the non-waxy. The waxy granules take on a mottled blue and red-brown coloration when stained with iodine.

Rye Starch.—Rye starch granules are similar in shape to those of wheat starch. The maximum diameter of rye starch granules may be as great as 60 microns. In the large, lens-shaped rye starch granules, the broadly stellate hilum is often very distinct. Rye starches usually contain fewer small spherical granules than are found in wheat starch.

Oat Starch.—Individual granules of oat starch are only 2 to 10 microns in diameter. The individual granules occur in compact spherical clusters, known as compound granules, about 60 microns in diameter (Pugh 1938). The compound granules are often broken as the grain is processed. The small individual granules are then observed to be polygonal, or rounded on only one side. Their shape results from the pressure against other individual granules within the compound granule. Lamellae are usually invisible. The hilum is faint or invisible. Birefringence is weak.

Rice Starch.—Rice starch, like oat starch, occurs in compound granules of 2 to 150 individual granules (Wallis 1933). The individual granules are chiefly 2 to 8 microns in diameter although a few may attain a diameter of 12 microns. In other respects, rice starch has a microscopic appearance much like that of oat starch.

Waxy rice starch is distinguished from ordinary rice starch by the reddish coloration which the former assumes when stained with iodine.

Composition of Starch Granules

Carbohydrate.—It has long been known that starch is a high molecular weight condensation polymer of glucose. The polymer is formed through loss of one molecule of water for each molecule of glucose. Since early in the 19th century, there has been indirect evidence of two fractions in most starches. Many attempts were made to separate them, but it was not until 1941 that Schoch (1941, 1942) and Wiegel (1941) obtained selective precipitation of one fraction by certain alcohols. The fraction that is thus precipitated is now known as A-fraction, or amylose; the portion that remains unprecipitated is known as B-fraction, or amylopectin. The terms "amylose" and "amylopectin" were used quite differently in

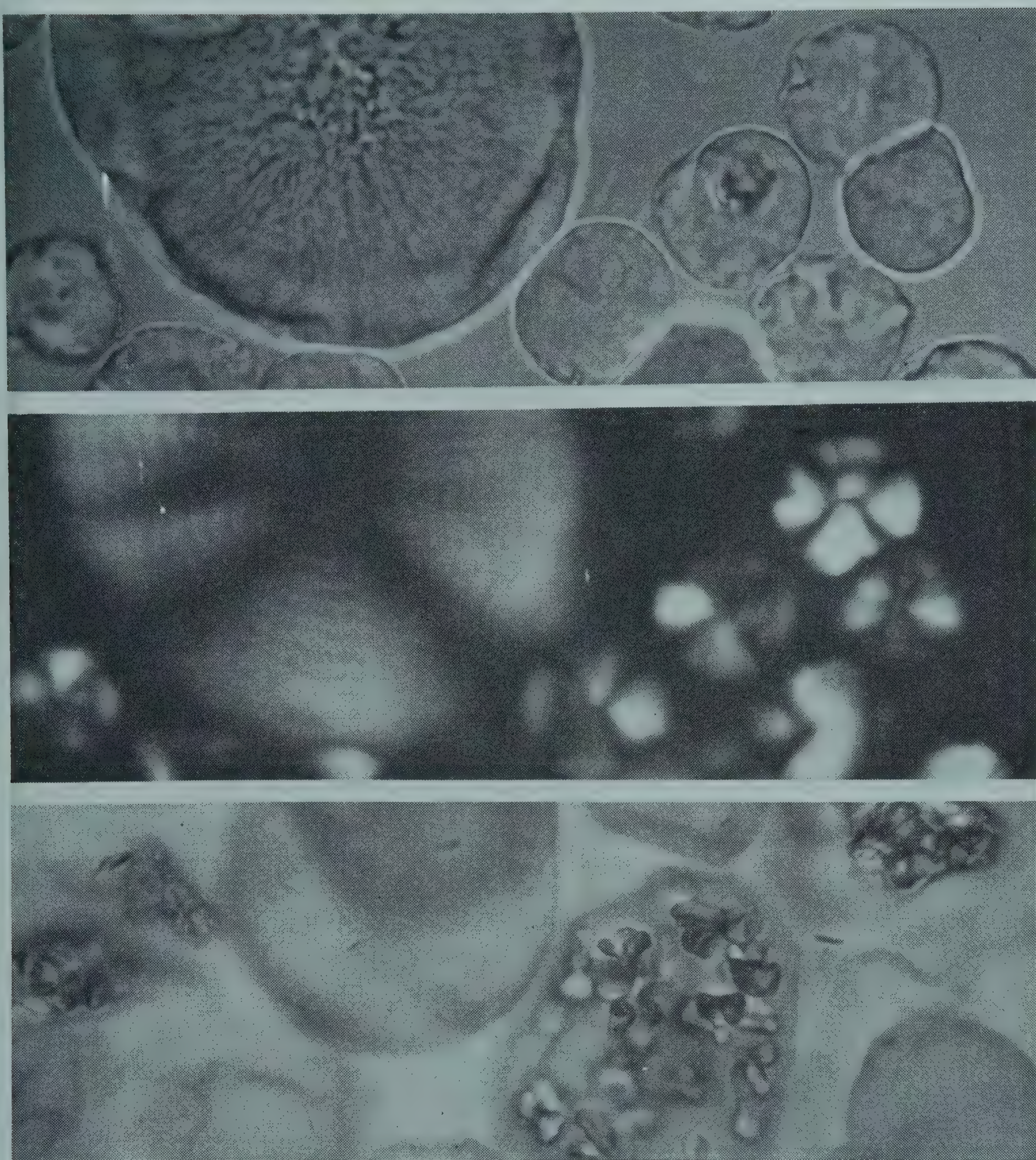


FIG. 150. CRYSTALS OF FATTY ACID-AMYLOSE COMPLEX

Upper: Separated at 194°F. from autoclaved cornstarch paste to which palmitic acid was added.
Center: Same as above, showing birefringence.
Lower: In sorghum starch held in water at 176°F. for 9 days.
Magnification 600×

earlier literature. In reading books and papers written prior to 1941, great care must, therefore, be taken in interpreting these terms.

A-fraction, or amylose, has since been selectively precipitated by many polar organic compounds capable of hydrogen bonding. Schoch and Williams (1944) showed the possibility of fractionation with fatty acid, and both fatty acids and soaps were found by MacMasters *et al.* (1946)

to be effective fractionating agents. Bear (1944) used a variety of organic compounds, including lower ketones and certain derivatives of benzene, as well as aliphatic alcohols and fatty acids. Nitroparaffins were the reagents preferred by Whistler and Hilbert (1945), although they found that many classes of organic compounds, including esters, ketones, mercaptans, carboxylic acids, nitroparaffins, and pyridine, could serve for fractionating starch. Capability of forming hydrogen bonds with amylose was considered to be the criterion for a fractionating agent.

Other fractionations have been reported. A recent development is fractionation by use of inorganic salts. This is the basis of the commercial fractionation of potato starch in the Netherlands (Hiemstra *et al.* 1956). A sedimentation procedure following extraction of amylose from pre-treated granules was used by Montgomery and Senti (1958).

The present major significance of fractionation to the food industry is the ease with which fatty-acid amylose complex forms at temperatures between 176° and 203°F. This complex may occur in a variety of food products, such as thickened soups and gravies.

The amylose content of starch can be estimated with some degree of accuracy without resort to actual fractionation. Bates *et al.* (1943) developed a method to determine amlyose content by potentiometric titration with iodine; the method is usually employed as modified by Wilson *et al.* (1943). A spectrophotometric method for starch determination was adapted by McCready and Hassid (1943) to determine amylose content; further modifications have been made in several laboratories. The potentiometric method depends on the observation that under the conditions used one gram of amylose binds about 200 mg. of iodine while amylopectin molecules bind a negligible amount. Several workers have demonstrated the presence in some starches of a fraction intermediate between amylose and amylopectin in iodine-binding capacity.

Study of the two major fractions of starch has shown that amylose is composed of linear molecules in which the glucose residues are joined chiefly through α-1,4 linkages. Amylopectin has a bush-like structure containing primarily α-1,4 linkages, but the molecule is branched through α-1,6 linkages. Evidence for the structure of starch fractions was reviewed in detail by Hough and Jones (1953) and Schoch (1953). Diagrams of portions of amylose and amylopectin molecules, to show structure, are depicted in Fig. 151.

The relationship of amylose and amylopectin to each other within the starch granule has not been clearly established. Indeed, some workers (Pascu and Hiller 1946, Sutra 1947) consider amylose and amylopectin to be degradation products, rather than true fractions of starch. As Schoch (1953) pointed out, there are several objections to this concept.

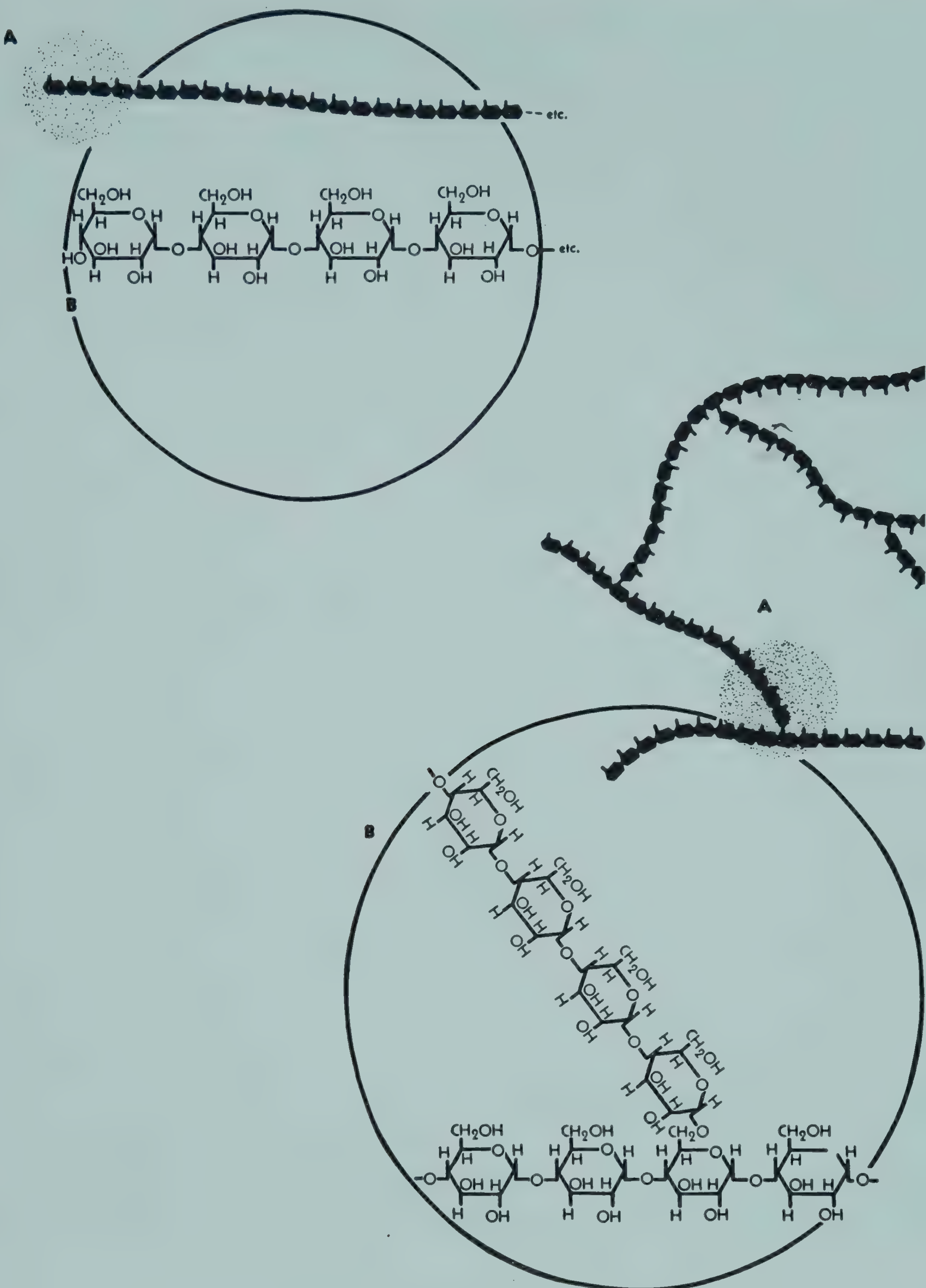


FIG. 151. REPRESENTATION OF PORTIONS OF AMYLOSE AND AMYLOPECTIN MOLECULES

B represents an enlargement of the shaded portion, A, in each instance.

Cereal starches usually contain approximately 25 per cent amylose and 75 per cent amylopectin. Waxy starches contain little or no amylose. Because they form long, viscous pastes which are translucent and retrograde only slowly, starches from waxy varieties of corn and sorghum have found use in such foods as pie fillings and puddings.

Amylose also has unique industrial possibilities, hence breeding programs are in progress to develop corn with starch of high amylose content.

Starch of 82 per cent amylose content has been attained (Zuber *et al.* 1958) and a field-type corn with starch of 56 per cent amylose content (Deatherage *et al.* 1954) has been grown in sufficient quantity for intensive study of the starch properties (Wolff *et al.* 1955). A series of natural starches of varying characteristics can be expected to be available for industrial food uses within the next decade.

Non-carbohydrate.—Starch granules commonly contain small amounts of protein, fatty substances, and inorganic material. There is considerable evidence that some of the inorganic ions are chemically combined with the starch molecules. For example, phosphate is sometimes considered to be an integral part of the starch molecule. There is considerably less phosphorus in cereal starches, however, than in potato and some other starches.

There is little evidence to indicate if the protein and fatty materials are integral parts of the granule, are merely occluded during granule formation, or are adsorbed on the granule surface either while the starch is still in the plant or during industrial processing.

The non-carbohydrate constituents of starch are of relatively little importance in relation to food use, except as they affect the physical properties of the starch. Current theories as to the relationship between the carbohydrate and other constituents of starch granules have been discussed in detail elsewhere (Radley 1953).

The Pasting of Starch

When unmodified starch is heated in water, it eventually makes the familiar starch paste. The process can be conveniently divided into the two major steps described below.

Loss of Crystalline Structure.—Air-dried starch granules swell slightly when placed in cold water, but retain a crystalline structure. Sorption of water is apparently not confined to the granule surface (Hellman and Melvin 1950).

As a suspension of starch in water is heated to successively higher temperatures, several distinct changes take place. First, birefringence is lost around the hilum; then there is progressive loss of birefringence outward from the hilum until none remains. Different granules within the same starch sample begin to lose birefringence and finally become completely lacking in birefringence (isotropic) at temperatures differing by several degrees Fahrenheit. The term "gelatinization temperature" is used by many starch chemists to designate that temperature at which all granules in a given sample have lost all birefringence. The range in temperature between that at which the first granules begin to show loss of birefringence around the hilum and that at which all granules have lost all

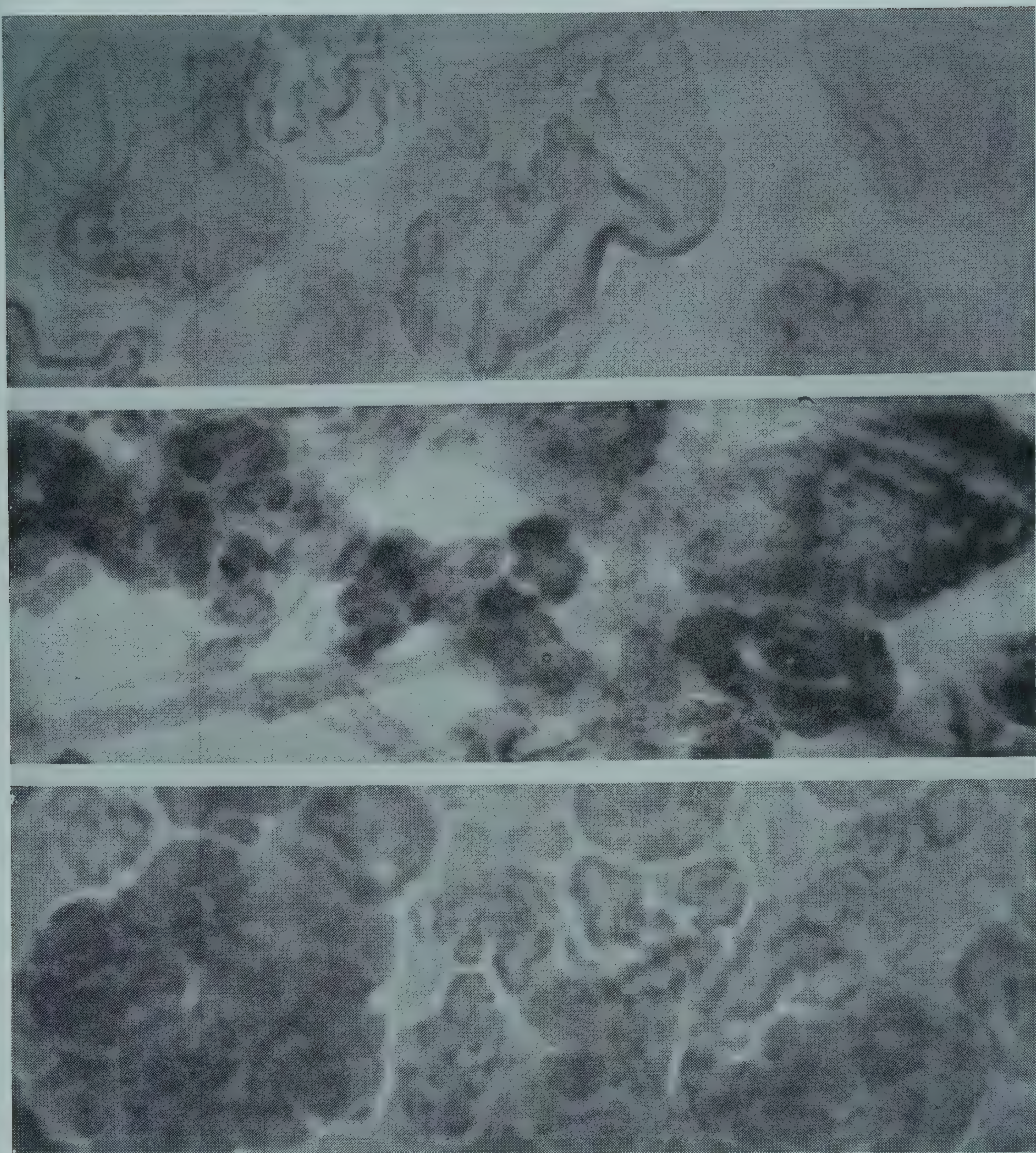


Fig. 152. Starch Granules After One Hour in Water at 203°F.

Upper: Cornstarch.
Center: Waxy cornstarch.
Lower: Wheat starch.
Magnification 525×

birefringence is then called the "gelatinization temperature range." Both are specific for a given starch and relatively specific for a type of starch, such as wheat, corn, or oat starch. The cereal starches cannot, however, be clearly distinguished from one another by their gelatinization temperatures or gelatinization temperature ranges. Most samples will show some loss of birefringence at 136°F. and nearly complete loss at 158°F.

If a polarizing microscope is not available for observation of birefringence, the gelatinization temperature and range may still be determined. An ordinary microscope may be used to observe staining of the granules with Congo red, congocorinth, or benzopurpurin, for example. These stains impart a red color to all gelatinized granules and gelatinized portions of granules. All ungelatinized portions remain unstained. It is sometimes convenient to use one of the stains in a preparation being examined under the polarizing microscope, to facilitate the observations. These techniques are often useful in identifying and estimating relative percentages of ungelatinized and gelatinized starches in foods and feeds.

Granules that have merely gelatinized and that have not swollen appreciably after gelatinization appear to retain the ability to return to the spherocrystalline state. If alcohol is used to dehydrate them, for example, they regain approximately their original size and again show strong birefringence. Addition of iodine reagent will effect a similar change in appearance (MacMasters 1953).

Swelling and Paste Characteristics.—As the temperature of an aqueous suspension of starch is increased above the gelatinization temperature, the granules swell considerably and quickly lose their ability to return to the birefringent condition. The shape of the swollen granules is characteristic for a given starch (Fig. 152). Amylose is lost from the granules into the ambient water. When a dilute, unagitated suspension is stained with iodine reagent, the granules are seen to be unbroken, with blue coloration resulting from the presence of amylose between them. Nonwaxy cereal starch granules, and most others, remain unbroken even in boiling water unless they are jostled by other granules or the suspension is mechanically agitated (MacMasters *et al.* 1947). When they are broken, the fragments remain as intact particles. A starch-water system must be heated under pressure well above the boiling temperature of water if the starch is to be dispersed.

The swelling of the granules as the temperature of the water is increased causes an increase in the viscosity of the system. Some workers refer to the temperature at which viscosity begins to increase rapidly as the "gelatinization temperature," but a more descriptive term, "swelling temperature," is used by many. Since "gelatinization temperature" is also used to indicate temperature at which all birefringence is lost, care must be taken to interpret the term if the author fails to define his meaning.

Within ordinary working limits, increased duration of heating cannot be substituted for temperature attained to produce a desired degree of swelling of starch granules. It is true that granules will swell slightly beyond the original amount if held in water for several hours at a con-

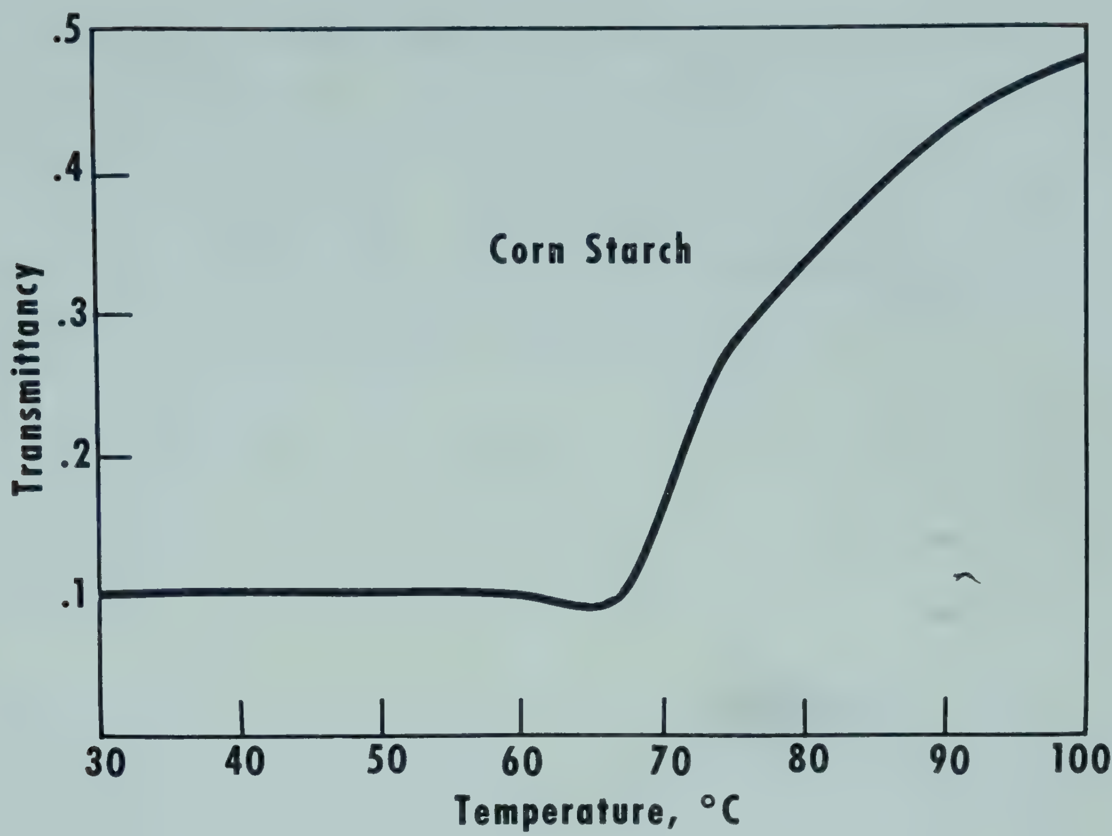


FIG. 153. LIGHT-TRANSMITTANCY CURVE OF CORNSTARCH HEATED IN WATER

stant temperature. But the increase thus attained is less than that caused by raising the temperature 10° to 20°F. If non-waxy starch is heated in water to 176° to 194°F. and held at that temperature for several days, the granules decrease slightly from the maximum swollen size which they attain, and become very tough. They can then no longer be broken by usual conditions attained in a high speed electrical homogenizer. Crystals of the fatty acid-amylose complex may form within some of the granules under these conditions (MacMasters *et al.* 1946), but often are found between the granules (Fig. 150).

Not only the microscopic appearance of the swollen granules, but also the characteristics of the paste depend on the kind of starch. Wheat starch, for example, forms a relatively soft paste while cornstarch pastes are stiffer. Both corn and wheat starch pastes are short. The waxy cereal starches form long pastes, which are initially much more viscous than those of the corresponding non-waxy starches. Waxy starch granules appear to break more easily than other starch granules during pasting (Fig. 152). Waxy rice starch, however, appears to suffer less breakage than the waxy starches of larger granule size. Waxy rice flour paste was found by Hanson *et al.* (1953) to be highly resistant to changes that starch pastes usually undergo during freezing.

The clarity of a non-waxy paste increases as the granules swell and become more translucent. The translucency curve obtained by plotting light transmittancy *vs.* temperature is characteristic of the kind of starch (Morgan 1940). The common cereal starches form semi-translucent

pastes (Fig. 153), which become more opaque with time. The opacity results from the tendency of the molecules, especially those of amylose, to align side by side with each other into relatively compact masses. The phenomenon is termed "retrogradation." Retrogradation occurs within a few hours in the case of ordinary cereal starches. Pastes of the waxy starches, on the other hand, are clear and translucent, and they retrograde very slowly.

Another characteristic of starch pastes, which may be of considerable importance in food applications, is their tendency to form coacervates. Coacervation is the separation of a colloid-rich phase from a colloid-poor phase. The separation may occur as a layering of the fluid system or the

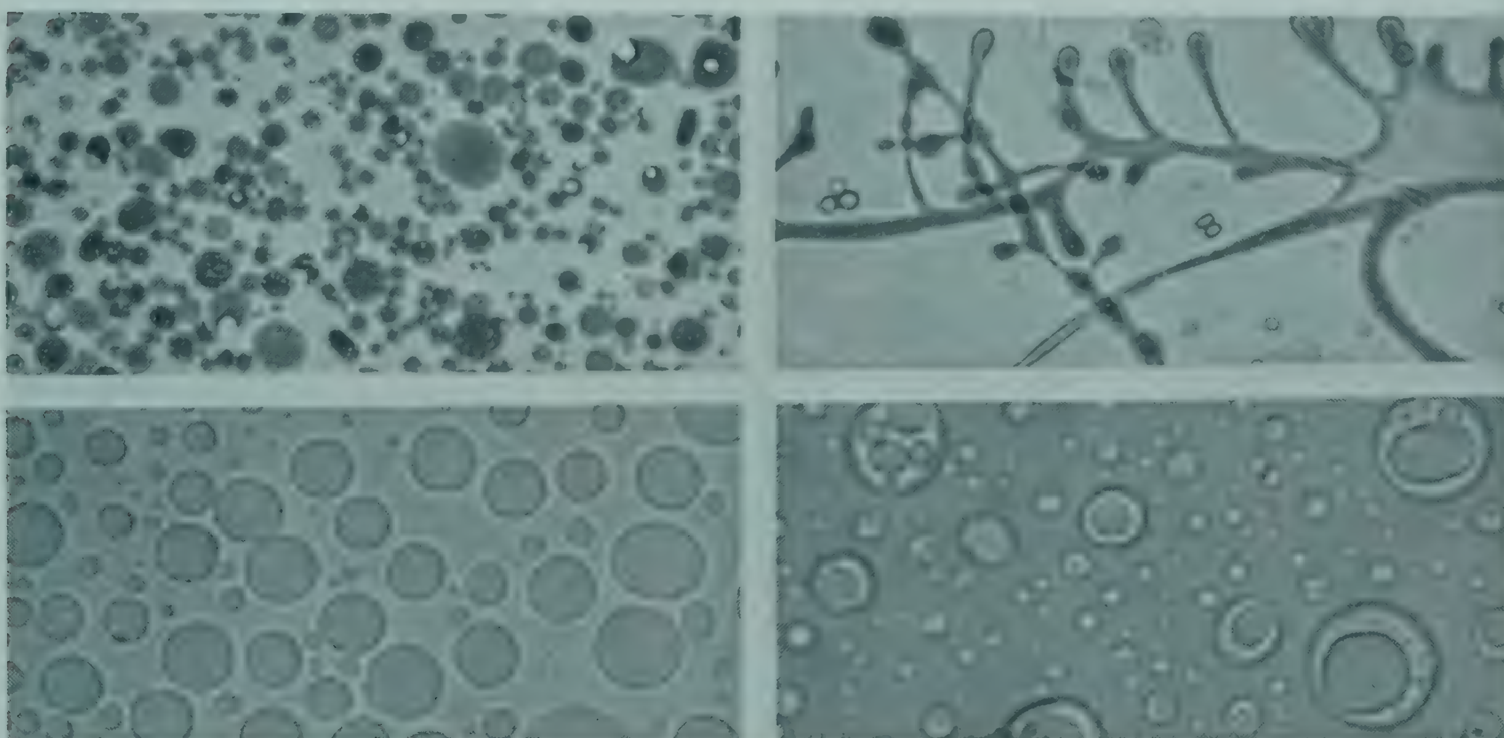


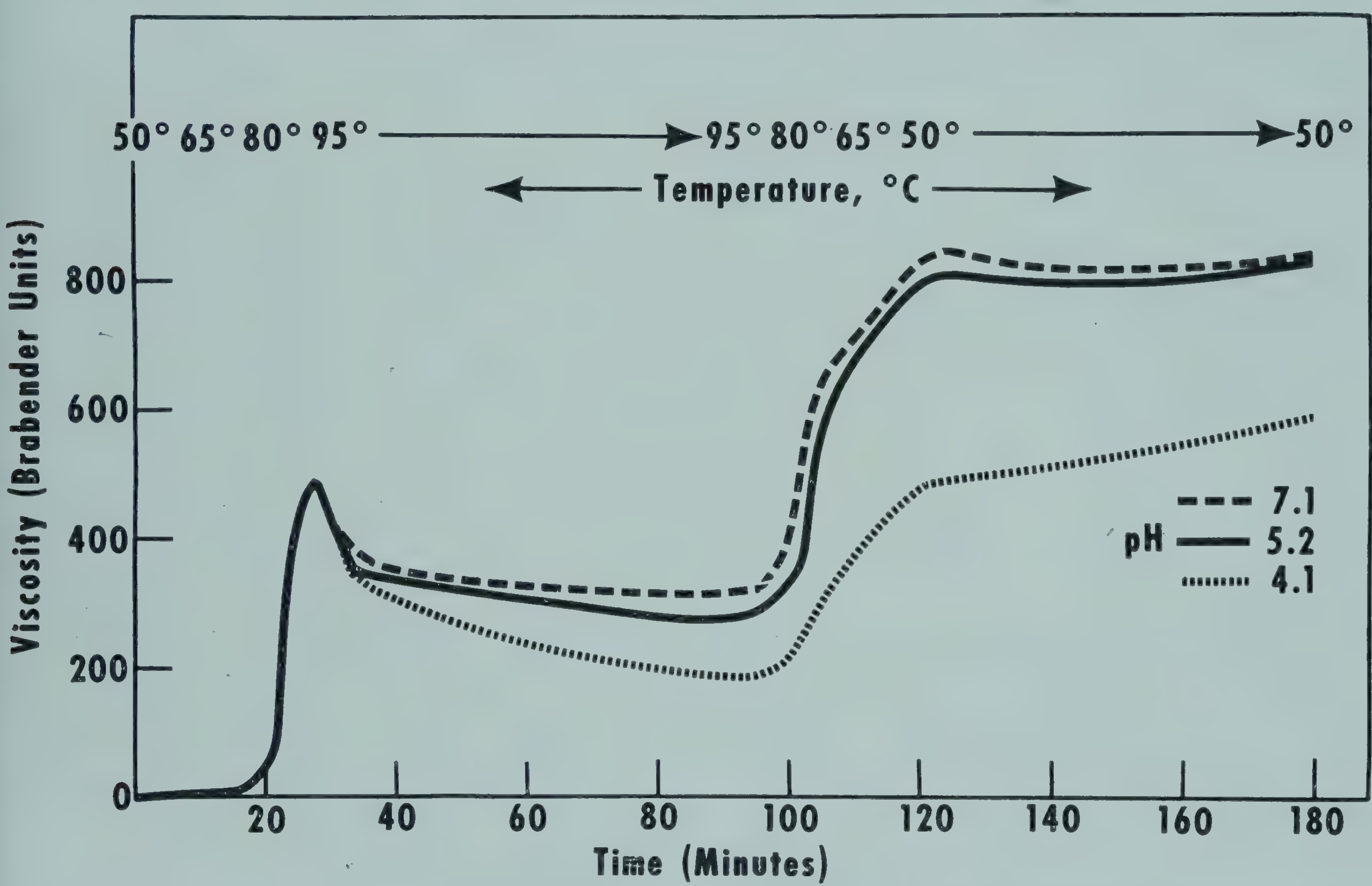
Fig. 154. Coacervates of Cornstarch

Upper: Droplets and myelin structure after freezing a 0.5 per cent paste.
Lower: Droplets in paste to which chloral hydrate was added.
Left, one minute after addition; right, five minutes after addition
Magnification 200×

coacervate may form as droplets or myelin structures. The spongy form assumed by a starch paste during slow freezing apparently results from coacervate formation. Possibly the lumpiness of some frozen sauces and gravies after thawing may be the result of coacervation during freezing. If the frozen paste is sufficiently dilute, typical myelin coacervate forms and droplets are obtained (Fig. 154) (MacMasters *et al.* 1946). In some other starch systems, only coacervate droplets appear (Fig. 154).

Paste Viscosity.—The viscosity of a starch paste is an important factor in its applicability to food uses. For example, it is the viscosity of pasted starch which leads to the use of flour or starch as a thickener in gravies and sauces.

Many instruments have been used to determine the viscosity of starch pastes. Capillary types are unsuited for this purpose because swollen starch granules either entirely fill the capillary or fill so much of it that abberant wall effects result. The same disadvantage holds for the Höppler viscometer when a large ball leaves an essentially capillary space between ball and wall. If a small ball is used, it is difficult to observe its fall through a semiopaque paste. Many useful studies have been made with the Corn Industries viscometer (Bechtel 1947) and the Brabender Amylograph (Schoch and Elder 1955, Kite *et al.* 1957), although these instruments introduce some turbulence to the paste. Least objection-



Data of E. G. Mazurs, furnished by T. J. Schoch

FIG. 155. RELATIONSHIP BETWEEN VISCOSITY OF A 6.8 PER CENT CORNSTARCH PASTE AND ITS pH

able from the theoretical point of view is probably the MacMichael viscometer. Starch pastes are, however, complex, non-homogeneous systems and only "apparent viscosity" should be reported for them.

Paste viscosity increases as the starch granules swell in hot water and occupy more space in the system. Loss of solubles (chiefly amylose) from the granules into the surrounding water increases the viscosity of the system. The swelling power and solubilization of several cereal starches have been reported by Leach *et al.* (1958), who found that "the extent of solubilization during pasting generally parallels the swelling pattern." The rate of agitation used was so slow that no granule fragmentation or

deformation was produced. This was confirmed by microscopic examination.

Concentration of starch, kind of starch, temperature attained by the starch-water system, duration of heating at that temperature, and degree of agitation of the system affect the viscosity of a starch paste, as shown in Table 118 (MacMasters *et al.* 1947). The pH of the system is also a factor.

Reaggregation may occur in cereal starch pastes when heating is prolonged after some or all granules have been disintegrated by rapid stirring. When the aggregates occur in considerable amount, as they do in some cereal starch pastes, they must influence the paste viscosity. The aggregate particles are usually elongated, rather than spherical. They were shown by MacMasters *et al.* (1947) to contain fatty material associated with amylose and a small amount of amylopectin. The particles appear to result from spontaneous formation of an impure fatty acid-amylose or soap-amylose complex. Fatty material in the presence of pasted starch in foods can increase the amount of the complex beyond that found in the starch paste alone. There have been cases where granulation in soups and gravies apparently could be attributed to formation of the complex.

TABLE 118

EFFECT OF SOME FACTORS ON PASTE VISCOSITY OF CORNSTARCH

Starch Concentration Per cent	Temperature °F.	Time at Temperature Min.	Stirring R.p.m.	Granule Breakage (Microscopic)	Apparent Viscosity C.p.
3	194	30	120	None	15
5	194	30	120	None	1,080
5	194	30	1,800	Appreciable	317
5	212	30	160	Appreciable	754
5	212	30	1,800	Complete	90
10	194	30	120	None	11,800
10	194	30	1,000	Unappreciable	7,290
20	212	30	1,000	Complete	18,500
20	212	60	1,000	Complete	9,480

Cereal starches exhibit considerable individuality in their paste viscosity characteristics. Cornstarch gives a short paste of moderately high viscosity which is fairly stable during cooking, but which is unstable below pH 4. Sorghum starch is similar to cornstarch, but T. J. Schoch reports (personal communication) that it requires more cooking than cornstarch. Wheat starch has a somewhat lower paste viscosity than that of corn or sorghum starch. Barley, rye, and wheat flours, as well as barley and rye starches, exhibit viscosity characteristics similar to those of wheat starch. Waxy corn and sorghum starches yield long pastes of very high maximum viscosity, but the viscosity decreases rapidly during cooking. Waxy rice

starch and flour have only moderate maximum viscosity that is relatively stable during cooking. The flour has less thickening power than the starch (E. G. Mazurs, through T. J. Schoch, personal communication).

Because of the varied characteristics of different starch pastes, it is often possible to choose a specific starch to attain the desired thickening in such foods as cream soups, salad dressings, canned vegetables, and baby foods.

Setback and Gel Characteristics.—When a starch paste is allowed to cool, it becomes more viscous. This change is known in the industry as "setback." The common cereal starches and flours have high setback, whereas the waxy cereal starches exhibit very little setback. As room temperature is attained, the starch pastes may set to a more or less rigid gel, depending on the kind and concentration of starch and the pH of the system.

There appears to be some relation between the size and shape of non-waxy starch granules and their gel-forming abilities. This relationship may be because of differences in molecular size which accompany the variations in granule size and shape. Cornstarch pasted in five per cent concentration sets to a stiff gel, typified by homemade cornstarch pudding. Wheat starch forms a much softer gel at a like concentration. Rice and oat starches form soft masses which appear more like cold pastes than gels. This seems to be a characteristic of gels of starches with small granule size.

The waxy starches form soft, thick masses rather than stiff gels. This characteristic, together with the clarity and slow retrogradation of waxy corn and sorghum starch pastes, makes these starches useful in fruit pie fillings and similar products.

MODIFIED STARCHES

For a number of applications in the food industry, starch is altered by the use of various physical and chemical procedures. Native granular cereal starches are efficiently digested by animals; modification probably has no bearing on their biological utilization (Booker *et al.* 1951). Rather, starch is modified specifically to confer upon it the special properties required or desired by food manufacturers for use in preparing end products such as canned foods, candy confections, bakery products, and beer. The end use determines the properties considered most desirable. For example, gum drops require a starch with proper gel strength and structure. In pie fillings and gravies non-gelling properties are more important. For use as a neutral edible filler, flow properties and acceptable color and odor may be most desired.

Because needs are diverse, a large number of tailor-made starch modi-

fications are marketed for food use by starch manufacturers. Among the desired improved properties gained by appropriate treatments of granular starch are whiter color, freedom from odor development, improved gel strength and clarity, higher enzyme susceptibility, lower bacterial count, improved flow characteristics (mobility) as a dry powder, greater paste stability, paste viscosity in the desired range—either higher or lower than that of the parent starch, and greatly increased water absorption in the cold. Many additional properties could be listed.

Types of modified starches for food uses referred to in this chapter could be derived from any cereal starch. In practice in the United States, however, they are largely derived from cornstarch. Some modified wheat and waxy cereal starches are also marketed. As an example of the many individual types of products proposed for food application, Schoch and Elder (1955) have listed a number of references to the patent literature. Brief references to starch modifications in commercial usage in the food industries in the United States have been collected and the products conveniently categorized according to general type of modification and to functional properties (Anon. 1958).

In addition to the various modifications of granular starch sold in powdered form, two research products proposed for use in the food industries can be mentioned. These are starch sponge and self-supporting film prepared from starch fractions, both of which would have applications based upon their physical form and properties.

Physically Modified Starches

The properties of starches and starch pastes are dependent largely upon the molecular organization found naturally in the granules. Disruption of this ordered arrangement would be expected to, and does, alter the characteristics and, hence, the end uses of the starch.

Pregelatinized Starches.—Unmodified starch does not form a paste in cold water. Cooking is, therefore, necessary to develop the properties required in a food thickening agent. To provide a product suitable for instant, convenient use by the consumer, the starch industry markets precooked or "pregelatinized" starches which readily form viscous pastes or gels in cold water.

Production of precooked starches is straightforward, although modifications are many. In essence, the starch is gelatinized and swollen in hot water and then dehydrated by passage through hot rolls or by spray drying. Extent of gelatinization is controlled by the amount of water used, and by temperature and time of treatment. Extent of granule destruction depends also upon the type of agitation or homogenization employed. Alternatively, gelatinization may take place *in situ* on the heated

rolls, when a starch slurry or wet starch filter cake is passed through them. The resultant dried product is usually ground before marketing. Properties of these cold-water-swelling starches are dependent upon the specific processing conditions selected, a number of which are described by Kerr (1950). Processing conditions affect the extent to which the granules are swollen and disrupted. Usually the pregelatinized starches yield pastes similar to those obtained by heating aqueous suspensions of the parent starches.

Pregelatinized starches are used in pie fillings, instant puddings, soup mixes, salad dressings, prepared breakfast cereals, bakery mixes, and in other applications where a thickening or stabilizing agent is required that can be used without resort to heating. Pregelatinized starches have also been used to improve the flow characteristics of cracker doughs (Kerr 1950). As water absorption and retention agents, they are used in marshmallows to obtain a tender texture and in meat products as binders. Special partially gelatinized starches are prepared in the form of grits for the brewing trade. Starch in this form is rendered more susceptible to enzyme action. Pelleted pregelatinized products of the type used in pearl tapioca puddings have been prepared from corn and waxy cornstarches (Schopmeyer 1947) and also from waxy sorghum starch (Martin 1944).

In practice, both unmodified starch and many starches modified by acids, oxidizing agents, or derivatization are available in pregelatinized, cold-water-swelling form.

Starch Sponge.—When a 5 to 10 per cent starch paste is slowly frozen and then thawed, the starch remains in a spongy form which can be squeezed and dried to a brittle, porous mass. Dried starch sponge readily absorbs 16 times its own weight of water. This novel form of starch has been proposed in ground or shredded form for holding excess moisture in preventing slipping and melting of icings, or as a crunchy ingredient of candies. In compressed form containing flavoring and possibly vitamins it is suggested as a concentrated carbohydrate for emergency or sportsmen's rations (Hilbert *et al.* 1945, MacMasters and Blom 1945). Sponges formed from wheat and cornstarches have been reported to differ in properties (Woodruff and Hayden 1936).

Films.—Transparent self-supporting films have been prepared in the laboratory from the linear (amylose) and branched (amylopectin) starch fractions and their properties determined (Wolff *et al.* 1951), including permeability characteristics (Rankin *et al.* 1958). In view of increasing interest in and availability of starch fractions as raw materials (Anon. 1957, Zuber *et al.* 1958), products derived from the fractions warrant serious consideration for potential uses. Amylose film is generally similar

to regenerated cellulose films in properties, although its wet strength is considerably lower. Amylose offers the advantage of greater ease of solution than dissolving pulp from paper wood or cotton; hence, xanthation is unnecessary for solution before conversion to film form. Amylose film is acted upon by digestive enzymes. Because of this fact and the other characteristics of the film, it could serve as an edible wrapper for food materials. Amylopectin film is more brittle, generally weaker mechanically than amylose film, but instantaneously soluble in water. Future research should include consideration of amylopectin film as a possible wrapping for individual packets of materials such as instant tea, laundry starch, and dyes, where a premeasured quantity of the ingredient and the packet itself would be utilized as a unit by the consumer.

Chemically Modified Starches

In the chemical modification of starch only a slight alteration of molecular structure is required to effect a drastic change in properties. For this reason, as well as for cost considerations, chemically modified starches used in the food industry have actually been changed to only a small degree. In some instances, perhaps only two-tenths of one per cent of the monomeric anhydroglucose units have been affected by the reagent used. In many cases the detailed chemistry involved in the conversion is complex and incompletely known. The consistent production of treated starches having desired properties still requires considerable art.

Types of modified starches most frequently used in food industries are acid modified—thin boiling starches, oxidized starches, and chemically derivatized starches.

Acid-Modified Starches.—The high viscosity of aqueous starch pastes is due both to the mechanical interaction of swollen granules and to dissolved starch molecules. High viscosity in dilute solution is characteristic of long-chain polymeric substances; in a given homologous series the higher the molecular weight the greater the viscosity. Linkages between the units of the starch chain are hemiacetal in type and are known to be broken by acid. Thus it would be expected that acid treatment of starch would shorten the starch chains. Products having lowered paste viscosity would result. That is the case. Wolff and Seckinger (1950) showed by viscosity studies on fractions derived from acid-modified starches that chain shortening occurs in both the amylose and amylopectin fractions.

Acid treatment also renders the granules more fragile and easily broken during pasting. This result contributes largely to the lowered viscosity of pastes from acid-modified starches. The greater ease of granular fracture after acid modification is thought to be due to preferential attack of the reagent upon the amorphous, more accessible areas of the granule.

These weakened areas permit easier disintegration of the granule upon heating in water.

With acid-modified starches, higher solids concentrations are possible at useful viscosity levels or, conversely, lower working viscosities are attained at equivalent concentrations. This flexibility is important in certain food technological applications. Acid-modified starches have other desirable characteristics referred to later in conjunction with specific applications.

Acid-modified starches are prepared commercially by modification of the starch granules without appreciable swelling or disruption. Hence, the treated starch may be readily filtered and remains insoluble, so processing losses are very small. A typical acid-modified starch may be prepared by heating a stirred starch slurry for 6 to 24 hours in dilute (about 0.1 *N*) sulfuric or hydrochloric acid at a temperature (often about 122°F.) below the gelatinization range of the starch. After neutralization the starch is recovered by filtration, washing, and drying.

The hot paste viscosity of starch is reduced upon acid modification. The pastes are exceedingly prone to gel on cooling, however, and form firmer gels than those from unmodified starch. Acid-modified starches are for this reason especially suited for the preparation of gum drops, jelly beans, and similar candy confections. This comprises one of their chief uses. Most frequently utilized products are modified cornstarches referred to in the trade as "40 fluidity" and "60 fluidity" grades. These designations refer to an empirical viscosity procedure used as a measure of the extent of starch modification by the acid. The starches yield products with the proper type of tender, yet firm gel having adequate clarity, solids content, and water retentiveness. Acid-modified starches have also been used as ingredients of ice cream cones and wafers.

The increased gelation tendency of starches upon acid-modification probably results from the formation of linear chains of just the proper length for alignment side-by-side to make crystallites with strong interchain bonds. It is possible also that more or less linear fragments of amylopectin are separated during hydrolytic treatment and contribute toward the gelation properties of the system.

Oxidized Starches.—Oxidation provides a versatile tool for modification of starch properties. By the proper selection of oxidizing reagent and of reaction conditions starches can be obtained having: lowered viscosity, increased viscosity, greater stability and clarity of pastes, reduced bacterial count, better whiteness, absence of odor, and improved mobility as a dry powder. Peroxides, permanganate, ozone, dichromate, gaseous oxygen, persalts, and many other reagents have been employed. Chlorine,

halite, and hypohalite salts are most frequently used in commercial modifications.

Even the most drastically oxidized commercial food starch involves modification of but a minor proportion of monomeric units. The exact nature of the changes taking place are not well understood. Oxidation of aldehyde end groups to carboxyl, oxidation of alcohol groupings to carbonyl and carboxyl, and chain scission either at carbon-to-carbon or at carbon-to-oxygen linkages to give smaller fragments probably all occur to varying extents. The degree to which each of these reactions occurs is doubtless dependent upon the reagent and experimental conditions used. Valuable investigations have made a small beginning in extending our knowledge of the specific chemical changes taking place during the oxidation of starch (e.g., Whistler *et al.* 1956). However the systems studied have differences from those employed in commercial practice, and one can say that the art of starch oxidation is considerably ahead of the science.

As in the acid-modification of starch, oxidation is effected without granule disruption. Thin-boiling oxystarches, that is those providing lowered paste viscosity than that of the original starch, are typically prepared in an alkaline suspension of sodium or calcium hypochlorite with the temperature maintained in the range 77° to 122°F. Amount of available chlorine, based on the weight of the starch, may be in the range of 0.5 to 8 per cent. Such products are characterized by improved paste clarity and decreased tendency toward gelation or deposit of insoluble material from the pastes (usually referred to as retrogradation). It is hypothesized that this lessened propensity to retrograde is attributable primarily to action of the oxidizing reagent on the linear fraction. Regularity of the amylose molecules is then disturbed to the extent that the chains do not associate as readily to form an organized network. Granules of oxidized, thin-boiling starches, like acid-modified starches, are fragile and easily disrupted on pasting; they have a short cooking time. If gels are formed, they are weaker than those from the unmodified starch.

Primary usage of the thin-boiling oxidized starches has been outside the food industries. The situation may change for it is said (Evans 1958) that products of this type have recently been developed which are free from flavor problems and are suitable for food use. Where paste stability and clarity are desired, as in some types of pie fillings, they are competitive with modified waxy starches or mixtures containing them, in which the desired properties are attained by utilizing the naturally different structure of the starch. Many factors such as texture and stringiness of pastes need to be considered in relation to specific applications. The thin-

boiling oxidized starches may be used as stabilizers in colloidal systems because of their high paste stability.

Oxidation of starch with chlorine or quite low quantities of hypochlorite can result in enchancement of paste viscosity (Kerr 1950). One explanation given for the viscosity increase, at least in some instances, is that the small amount of hypochlorite used reacts with residual sulfur dioxide (left in the starch as a result of its processing), thus preventing it from effecting a lowering of paste viscosity. However, the viscosity increase may be due to the establishment of some type of cross-linking, the nature of which has not yet been established. Use of such a thick-boiling starch provides the obvious advantage of lowering the amount of thickening agent required for a given application. Granular starch treated in aqueous suspension with chlorine results in a product with up to five times its original hot-paste viscosity. Careful control of pH, temperature, time, and reagent concentration can give products having differing ranges of hot and cold paste viscosity, which vary somewhat independently. This variableness is important in securing products having proper flow characteristics when hot, for efficient processing, but still possessing the desired thickening action after cooling. Thick-boiling oxidized starches are useful in canning operations because of higher than normal resistance to viscosity breakdown. They are also used in the preparation of soups, sauces, and other food products in which high thickening power is desired. The products are said, like the hypochlorite-oxidized thin-boiling starches, to have improved paste clarity.

Oxidation with chlorine, chlorite, and hypochlorite salts in aqueous suspension under mild conditions has also been used to improve mobility of starch as a dry powder, to render it bland in flavor, and to increase its water-absorption capacity. To prevent odor development on aging in starches used as food ingredients, such as an anticaking agent in powdered sugar or as an inert filling agent in baking powder, permanganate has been used in small quantities as an oxidant in aqueous starch suspensions. The oxidized starch is dried to a low moisture content of about five per cent (Kerr 1936). Incorporation of starch in baking powder is a major food use of starch and is unique in that it does not depend upon the paste or gel-forming property. Rather, its function is to hold moisture and to keep the active ingredients apart and from prematurely reacting with one another. Oxidation of an aqueous starch slurry with calcium peroxide has been said to yield a product with lowered hot-paste viscosity but which on cooling provides clear, strong gels for use in gum confections (Kerr 1941). Hypochlorite or permanganate (Sjostrom 1936) has been used to bleach starch to free it from yellow color. The various chemical bleaches also tend to sterilize starch (Kerr 1950).

Derivatized Starches.—Chemically, starch is a polyfunctional alcohol. Its hydroxyl groups can be converted to esters and ethers—chemical derivatives which may have properties quite different from those of the raw materials. Complete substitution of all hydroxyl groups is possible; triesters no longer have the typical starch property of forming aqueous colloidal solutions. The triesters are less polar than the original starch and are soluble in organic solvents such as chlorinated hydrocarbons. Amylose and amylopectin triesters are quite different from each other in characteristics and potential uses.

Commercial chemically derivatized starches retain the original granule form and contain only a small proportion of ester or ether groupings. One of the most useful groups of starches chemically modified for food use has been that cross-linked by employing polyfunctional reagents. If a reagent contains more than one hydroxyl-reactive grouping per molecule, one end can react with one starch molecule and the other end with a second starch chain. These cross-bonds then serve as "braces" which tend to fix the network of macromolecules rigidly in place so they are no longer free to move. Thus starch can be converted by aldehydes, dibasic acids, diisocyanates, epichlorohydrin, phosphorus oxychloride or similar reagents to products which are substantially unaffected in boiling water and which show none of the usual paste and gel-forming characteristics. Such resistant products have been prepared and used for dusting surgical gloves but generally speaking are not so valuable as those prepared with carefully chosen intermediate amounts of cross-linking reagent.

If only a few cross bridges, perhaps as little as 1 per 100 to 500 anhydroglucose units, are introduced, the ties prevent the starch molecules in the granule from being separated as rapidly or as completely as in the case of unmodified starch. An "inhibited" starch results, which does not gelatinize so easily in hot water and is less affected by acids and alkalies. It attains its maximum viscosity more slowly at elevated temperatures and the paste viscosity is not so prone to break down on prolonged cooking. A lower maximum viscosity may be achieved. Such modified starches are especially useful in canning and other processes where prolonged cooking or agitation may be involved. They are also useful in foods, like salad dressing, which contain acetic acid, or in fruit pie fillings containing natural food acids, where marked resistance to viscosity breakdown by the acid is needed. Waxy corn and sorghum starches especially are improved by cross-linking, because their pastes are prone to thin markedly on prolonged cooking. Waxy cornstarch cross-linked by phosphorylation gives pastes of reduced stringiness, good clarity, and reduced tendency to decrease in viscosity on prolonged heating. Evans (1958)

has published a partial list of patents revealing reagents and processes for preparing cross-linked starches.

Hydroxyethyl starches, prepared by reaction of starch with ethylene oxide, resemble oxystarches in furnishing pastes of reduced gelling tendency and improved clarity. Again the characteristics presumably result because the linear fraction is so modified that the molecules cannot readily become aligned. As little as one grouping for every 10 or 20 chain units is quite effective. Hydroxyethylated starches currently have no extensive use, if any, in foods but their potentialities for edible purposes are being assessed.

Many other starch derivatives have been prepared in various industrial, university, and government laboratories. These include partial esters of starch and also starch containing charged groupings. Some of these starches may have considerable potential for the food industry, but as yet they have achieved little or no actual usage. There is reluctance to introduce chemical derivatives for food uses because of the generally unfavorable public reaction to chemically modified materials in foods.

Variability among native starches in the clarity, viscosity, texture, and stability of pastes is considerable in itself. If to this wide range are added the numerous effects that can be achieved by varying cooking conditions, and the changes that can be superimposed on any one of these original products by chemical derivatization, the multitude of starches available for special applications is not surprising.

Other Chemical Modifications.—Many other chemical starch modifications have been proposed. Among them are treatment with dilute alkali to reduce protein and enhance paste clarity, and organic solvent extraction to purify the starch by lipid removal. These have achieved less practical importance than the modifications already described.

Other Modified Starches

Modification of starch occurs during breadmaking as a result of the presence of granules damaged in milling which thus become susceptible to the biochemical activities of the enzymes present in the dough. The properties of starch are undoubtedly affected by additives in the dough, such as oxidants and antistaling agents. These changed starch properties may be reflected in the characteristics of the bread produced.

Likewise, starch is modified enzymatically in the fermentation industries. The role of starch in processes such as industrial fermentation and breadbaking requires more detailed treatment than is possible in this chapter.

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Flavor Staling Resulting from Lipid Deterioration

INTRODUCTION

The phenomena of fat oxidation by atmospheric oxygen (autoxidation) and fat splitting by lipolytic enzymes have been studied extensively for many years. Generally, these investigations have been on a fundamental basis. Only recently have attempts been made to interpret experimental findings in terms of such natural changes as paint hardening, the mechanism of fat absorption by the living animal, and deteriorative changes taking place in food.

Once the transition is made from the simple system of the *in vitro* experiment to the complex situation occurring in nature, a multitude of difficulties beset the investigator. He is confronted with a series of enzyme systems which are interrelated; he must take cognizance of the daily fluctuations of temperature, humidity and, in some cases, light; he must remember that the material he is studying is not an isolated system, but one which is open to attacks by mold, bacteria, yeasts, and higher organisms such as insects and rodents.

This chapter is devoted to a consideration of the lipids—one component of cereal foods. It is the intention to review briefly the fat content of cereals and cereal foods including the more important characteristics of these fats, and then to discuss in considerable detail some of the changes which take place in the fats. Finally, there will be given a short description of the measures that can be taken to minimize some of these changes.

CEREAL LIPIDS

Fatty Acids of Cereal Lipids

At this point, it may be worthwhile considering in some detail the cereal lipids. According to Hilditch (1956) the most important fatty acids to be found in grain fats are:

Saturated:

Palmitic (*n*-Hexadecanoic)—$CH_3[CH_2]_{14} \cdot COOH$
Stearic (*n*-Octadecanoic)—$CH_3[CH_2]_{16} \cdot COOH$

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Unsaturated:

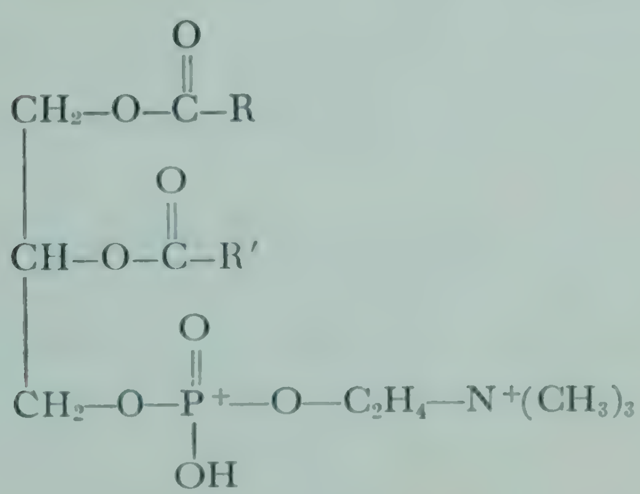
Oleic (Octadec-9-enoic)–$CH_3[CH_2]$ CH:CH$[CH_2]$ · COOH
Linoleic (Octadeca-9,12-dienoic)–
$CH_3[CH_2]_4CH$ · $CHCH_2$ · CH:CH$[CH_2]_4$ · COOH
Linolenic (Octadeca-9,12-15 trienoic)–
CH_3 · CH_2 · CH:CH · CH_2 · CH:CH · CH_2 · CH:CH · $[CH_2]_7$ · COOH

The make-up of the cereal grain fats is then as indicated in Table 119. These figures show that linoleic and oleic acids constitute well over two-thirds of the fatty acids present in cereal grains. The ratio of these two fatty acids varies considerably, however.

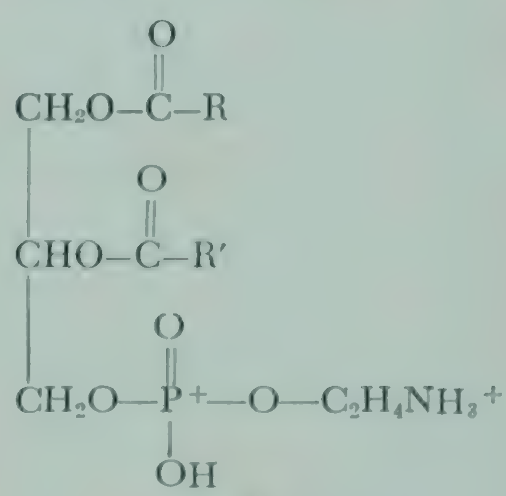
The quantity of fat to be found in cereal products is shown in Table 120.

Phosphatides

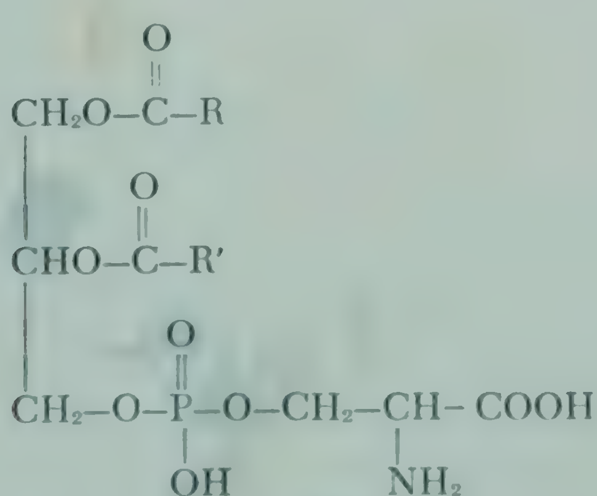
During the last decade, a second type of lipid component has received increasing attention. The name phosphatide will be used to describe that type of compound in which the esters of alcohols with fatty acids are attached to a phosphoric acid residue. Lecithin (I), cephalin (II), and phosphatidyl-serine (III) are examples of such compounds.



I



II



III

As is the case with glycerides, an infinite number of compounds can exist theoretically, each one differing from the others by the type of fatty acids found in the formula. In practice, however, it is found that

TABLE 119

THE COMPONENT FATTY ACIDS OF CEREAL GRAIN FATS

	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Other
			(Per cent by Weight)			
Wheat (germ)	11.8	3.0	39.0	30.0	6.0	0.3[1]
Corn (germ)	10.2	3.0	49.6	34.3	..	1.4[2] 1.5[3]
Oat (germ)	10.0	..	59.0	31.0	..	..
Barley (seed)	9.0	3.0	33.0	54.0	0.5	..
Rye	21.0		18.0	61.0	..	..
Rice	13.0		52.0	35.0	..	..

[1] C_{24} saturated.
[2] C_{14} saturated.
[3] C_{16} unsaturated.

TABLE 120

THE FAT CONTENT OF CEREAL PRODUCTS[1]

	Per cent by Weight
Wheat flour (12 per cent moisture)	
Hard wheat 80 per cent extraction	1.3
Hard wheat straight	1.2
Soft wheat straight	1.0
Self rising	1.0
Patent all purpose flour	1.0
Bread flour	1.1
Cake or pastry flour	0.8
Corn flour (12 per cent moisture)	2.6
Corn meal (12 per cent moisture) white or yellow	
Whole grained unbolted (12 per cent moisture)	3.9
Whole grained bolted (12 per cent moisture)	3.4
Degerminated dry (12 per cent moisture)	1.2
Self-rising dry (12 per cent moisture)	3.7
Oatmeal or rolled oats (8.3 per cent moisture)	7.4
Barley pearled, light, dry (11.1 per cent moisture)	1.0
Buckwheat flour (12 per cent moisture)	
Light	1.2
Dark	2.5
Rice milled (12.3 per cent moisture)	0.3
Rye flour (11 per cent moisture)	
Light	1.0
Medium	1.7
Dark	2.6

[1] Anon. (1950).

the fatty acids of the phosphatides bear a close similarity to the fatty acids of the glycerides found in the same organism (plant or animal) except that the phosphatide fatty acids tend to be more unsaturated. In soya bean, which is the most important commercial source of lecithin, unsaturated fatty acids make up some 70 per cent of the total weight of fatty acids.

Witcoff (1951) gives figures quoted in Table 121 for the phosphatide content of various oils from cereal grains and oil seeds.

TABLE 121

THE PHOSPHATIDE CONTENT OF VARIOUS OILS

	Per cent Phosphatides
Barley	3.4–4.2
Soy bean	1.8
Rye germ	1.3
Oat	1.0
Rice	0.5
Linseed	0.3
Millet	0.2
Rapeseed	0.1
Sesame seed	0.1
Wheat germ	0.08–2.0
Cacao	0.01

Phosphatidyl-amino ethyl alcohol, lecithin, cephalin, and phosphatidic acids have been reported as present in wheat phosphatides and the distribution of this type of lipid is 0.6 per cent in the whole grain, 1.6 per cent in the bran, up to 1.4 per cent in the flour, 1.8 per cent in the grits or middlings, 1.3 per cent in the germ, and 8.5 per cent to 11.1 per cent in the gluten. Witcoff reports that stearic and palmitic acids were found to be the predominant saturated fatty acids in wheat phosphatides and that linolenic acid with a small amount of oleic acid were the chief unsaturated acids.

In the case of corn, expressed oil is reported to contain 0.04 per cent phosphatides, whereas extracted oil can contain up to 0.5 per cent phosphatide. Investigations as to the type of phosphatides present are still in the early stages, but lecithin and phosphatidyl-amino ethyl alcohol have been recognized and a phosphatide containing inositol has been reported (Witcoff 1951).

The fatty acids of corn phosphatides have not been completely isolated, but at the present time palmitic acid is recognized as the chief saturated acid and linoleic and linolenic are the most important unsaturated acids.

Rye germ is reported to have a phosphatide content of 2.4 per cent, barley 0.16 per cent, and oats 0.14 per cent. In general, palmitic and stearic acids are the most important saturated acids and linoleic and linolenic the unsaturated acids present in greatest quantity.

MIXTURE OF FATS AND CEREALS

In addition to the lipids naturally occurring in cereals, it is customary to have present in prepared mixes, breakfast cereals, etc., fats which have been added to the food for some specific purpose, such as color and flavor enhancement, or texture improvement. Depending upon the type of

Table 122

THE COMPONENT FATTY ACIDS OF ANIMAL AND VEGETABLE FATS

	Palmitic	Stearic	Oleic (Per cent by Weight)	Linoleic	Linolenic
Corn	10.2	3.0	49.6	34.3	
Cottonseed		27.0	19.0	54.0	
Soya[1]		13.0	10.0–59.0	29.0–66.0	1.0–10.0
Peanut		20.0	50.0	27.0	
Hog[1]		30.0		70.0	

[1] Average of several samples.

Table 123

FAT CONTENT OF SOME BREAKFAST CEREALS AND PREPARED MIXES

	Moisture (Per cent)	Fat (Per cent)
Bran	2.6	3.4
Corn flakes	3.6	0.4
Rice flakes	3.5	0.6
Puffed rice	3.5	0.6
Puffed wheat	3.8	1.6
Oats, rolled	8.3	7.4
Layer cake mix	4.0	15.0
Pie crust mix	4.0	30.0
Crackers		
Graham	5.5	10.0
Saltines	4.6	11.8
Soda, plain	5.7	9.6
Cookies	4.8	12.7
Pancake mix	10.4	1.4
Corn meal (self rising)	12.0	3.7

food, the added fat will be of animal or of vegetable origin, be stabilized or unstabilized, emulsified, hydrogenated, liquid, or solid.

The most popular vegetable oils for use in mixes are corn, soya, cottonseed, and peanut, although vegetable oils from other sources may be used for specific purposes. Animal fats are beef or pork fats—lard being unique among fats for the excellence of its shortening properties. Generally the blend of the lard will change from time to time depending on the season of the year and the state of the market, but although the proportion of "killing fat" to "cutting fat" will alter, the meat packer will make every endeavor to provide a material with uniform physical properties. Recently, there has been a development in fat technology which has given rise to animal-vegetable fat blends and also a new process has been introduced in which, by the use of catalysts, the fat is "re-arranged," i.e., hydrolyzed to glycerol and fatty acids and then re-esterified. In this way, it is possible to obtain an even distribution of the fatty acids with the results that the physical properties of the fat are modified.

The major component fatty acids of bakery fats are shown in Table 122.

In the final product, then, the fat content is made up of the lipids occurring naturally in the fat plus the fat or shortening added as an ingredient to the mix. The fat contents of some typical foods are given in Table 123.

ENZYMES ACTING ON LIPIDS

Lipases

Having duly considered the lipid reactants, or substrate, it is pertinent to mention other components which are brought to the reaction system by the cereal ingredients. Perhaps the most important of these are the lipases and the lipoxidases, although other enzymes such as catalase, peroxidase, cytochrome oxidase, and a tyrosinase have been reported (Sullivan 1946). The function of the lipase and lipoxidase enzymes will be discussed in more detail subsequently. At the moment we are more concerned with the origin of these materials.

In the case of oats, it is claimed that the lipolytic activity may be removed by a wet dehulling process (Bradshaw 1952). A second authority claims that the activity is located in the region of the oat pericarp above the testa and not in the aleurone layer (Hutchinson *et al.* 1951).

In contrast, Sullivan (1946) in reviewing the subject of lipase activity in wheat, points out that the clear and low grade flours have a greater activity than patent flours, germ, or bran, and that the lipases are present in the greatest concentration in the scutellum and aleurone layers. Rather unexpectedly, the germ is not the source of greatest lipase activity.

The source of the lipase in corn is difficult to establish. It is popularly supposed that the highest concentration is to be found in the germ, but there seems to be a dearth of scientific support for this belief.

Lipoxidases

Turning now to lipoxidase, the enzyme which enters into fat oxidation reactions, very little information is available on cereals in general. Most published data concerns soya bean meal, although Sullivan, in her review (1946) mentions that the enzyme has been reported in wheat germ with an activity of 810 units which compares with an activity of 35,000 units for soybean meal. In spite of this lower activity, however, the enzyme may well become an important factor in storage stability of cereals and cereal mixes since the average storage life of such materials may extend to between six months and a year. In this time there would seem to be adequate opportunity for even an enzyme of relatively low activity to produce noticeable effects.

THE DETERIORATIVE REACTIONS

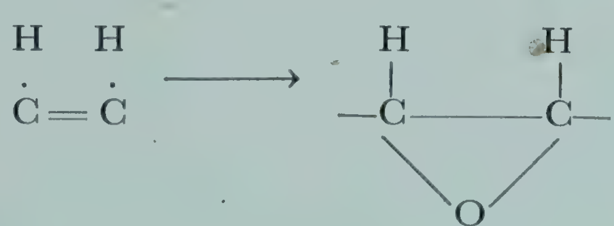
Types of Reactions

For purposes of the present discussion, it may be assumed that lipid deterioration in cereal products is due to one or both of two types of reactions, namely oxidation and fat hydrolysis. These two reactions are the basic cause of many types of deterioration including loss of flavor, color, development of off-odors, and even (with prepared mixes and bread) changes in volume and texture of the baked product.

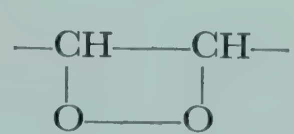
The following discussion will deal first with the process of fat oxidation and then with that of fat hydrolysis. The various factors such as heat, light, and moisture will be mentioned in relation to these reactions and the role of enzymes also will be dealt with.

Fat Oxidation Mechanisms.—Turning first to fat oxidation, much work has been done in an attempt to discover the mechanisms involved. Lipid deterioration in foods generally involves autoxidation, i.e., fat oxidation of unsaturated fatty acids by atmospheric oxygen, giving rise to such end products as aldehydes, ketones, and saturated fatty acids. These are often odoriferous compounds and may in turn react with other components in the food, and so increase the spoilage.

While it is by no means easy to identify all the reaction products of fat autoxidation, the task of determining the mechanism for this process is even more difficult. The main debate centers around the intermediate compounds formed and currently three reactions have been suggested (Markley 1947). The first would require the formation of ethylene oxide at the site of the double bond:



A second hypothesis requires the formation of cyclic peroxide:



and a third, the hydroperoxide theory, suggests that this type of compound is an intermediary in the reaction:

$$-CH_2 \cdot CH = CH- + O_2 \longrightarrow -CH(OOH)-C{=}CH-$$

The latter theory, developed by Farmer and his associates, goes on to suggest that the hydroperoxide then enters into secondary reactions with more unsaturated fat giving rise to epoxides and products containing hy-

droxyl groups. It is suggested that chain breaking may occur and that polymerization may take place. In the presence of iron salts, unsaturated ketones may be formed and if alkalies are present, the double bonds may be eliminated successively and hydrogen peroxide liberated. Farmer's theory has received considerable support due to the fact that it was found possible to isolate a peroxidized methyl oleate containing two atoms of oxygen and one double bond.

Measures of Fat Oxidation.—Whichever mechanism is responsible for the autoxidation of fats, several tests have been developed to measure the quantity of fat oxidation products that result. Perhaps the best known is Lea's Peroxide Test (Markley 1947) in which, under standard conditions, iodine is liberated from potassium iodide by fat peroxides and the amount of iodine so liberated is determined by a back titration against sodium thiosulfate with starch as an indicator. In the Swift Stability Test, the Lea test is used to measure the extent of peroxide formation in a fat maintained at a high temperature and aerated under standard conditions. If the quantity of peroxide is plotted against heating time it is found that the curve obtained moves slowly away from the time axis until a point of inflection is reached when it rises steeply in the direction of higher peroxide formation. The length of heating time necessary to reach the point of inflection in the curve is a measure of the stability of the sample fat. Such a test is currently used as a means of specifying a fat and generally 100 hours of heating is the minimum requirement for all vegetable fats.

Recently a third test has been devised, called the thiobarbituric acid test (Caldwell and Grogg 1955), which depends upon the development of a red color between thiobarbituric acid and lipid oxidation products. The optical density of the complex, read at 532 mμ, is proportional to the degree of oxidation of the fat.

Factors Affecting the Rate of Fat Oxidation.—As already indicated, a discussion of the factors affecting the development of rancidity in fats is necessarily an over-simplification in that each factor must be reviewed separately. In practice, however, each factor does not have an independent role, but exerts its influence in conjunction with many others.

It is a relatively easy matter to establish a relationship between the rate of oxidation of a fat exposed to air or oxygen, and the temperature at which the fat is maintained. As is customary with most chemical reactions, the higher the temperature, the more quickly will fat oxidize. With purified methyl oleate, for example, it is reported (Bailey 1951) that below 140°F. the rate of oxidation is doubled for each increase in temperature of 81°F. Above 140°F. the rate is doubled for each 19–20°F. rise in temperature. Other workers report a doubling interval of 16 to 29°F.

To relate this result to a more practical situation can be a matter of some difficulty. Suppose the experiment be carried out on a mix containing fat and flour, then as the temperature increases, not only does the rate of oxidation of the fat increase, but due to seepage and soaking up of the fat on the flour particles, the surface area of the fat is also increased. This, in turn, gives additional opportunity for the fat oxidation to take place. Should the fat-flour mix be contained in some fiberboard container, the fat will "wick" up the sides of the packet. Again the surface area of the fat is increased with the result that fat oxidation is promoted.

The moisture of the material with which the fat is mixed may also exert an influence on the fat oxidation. It is claimed that moisture has a stabilizing influence on fats in cereals and in crackers (Triebold 1945). As will be seen later, this is in contrast to the effect of moisture on fat hydrolysis.

Light has an adverse effect on fat stability. Particularly is this true of ultraviolet light where the presence of ozone produced by the ultraviolet light might further speed fat oxidation. It has been found that deterioration of foods containing high quantities of fat may be minimized by packaging in opaque containers or by covering with translucent material colored to exclude light of the shorter wave lengths.

Perhaps some of the most powerful promoters of fat oxidation are metals, particularly the heavy metals. Bailey (1951) reports that the stability of lard at 208°F. may be reduced to one half of the normal value by the following concentration of metals in parts per million:

Copper	0.05
Manganese	0.60
Iron	0.60
Chromium	1.20
Nickel	2.20
Vanadium	3.00
Zinc	19.60
Aluminum	50.00

When it is remembered that traces of metals, such as copper, manganese, and iron are to be found in cereal products, wrapping materials and enrichment ingredients, it is not surprising that the oxidation of fats is a common problem in the food industry.

Exerting an influence in the opposite direction are those trace components to be found in cereals and other mix ingredients which help to stabilize food fats. Such antioxidant materials include the tocopherols which are to be found in vegetable oils. Tocopherols, like synthetic antioxidants, can form synergistic mixtures with such materials as citric acid

and phosphoric acid and then exert a powerful retarding effect on fat oxidation. Although the subject of antioxidants will be discussed in the third part of this chapter, it is worth mentioning that the mechanism of action of the materials is thought to be that of an absorber for the energy necessary to promote a chain reaction. The chain reaction is thus interrupted and the oxidation of the fat slowed down. During the process of acting as an energy absorber, the antioxidant is itself oxidized.

Fat oxidation may be promoted by enzymes such as lipoxidase. This enzyme is thought to be involved in the natural aging that takes place in wheat flour on storage. Lipoxidase acts on unsaturated fats and upon the carotene in the cereal products. It has been reported that oxygen uptake with lipoxidase from durum semolina is a two-phase reaction (Irvine and Anderson 1953), with the initial rate following the classical Michaelis kinetics with a Km of 5×10^{-6} at a pH of 6.5 and a temperature of 86° F. The activation energy is 6,500 calories between 50° and 86° F. A routine manometric assay method has been worked out for measuring lipoxidase activity.

In a prepared mix, other ingredients are thought to have a significant effect on fat oxidation. Besides the antioxidants which occur naturally in the flour, and the moisture present, such materials as salt may significantly reduce the stability of the product (Lindemann 1953). This is particularly true in such materials as breakfast cereals. Sugar, on the other hand, is reported to have a mildly antioxidant effect.

Results of Fat Oxidation.—It has already been stated that the products of fat oxidation are often odoriferous, and many reports in the literature pinpoint fat oxidation as being responsible for many of the off-tastes, particularly bitter tastes, which develop in foods on storage. Fat oxidation products can change the color of foodstuffs, darkening or bleaching them, depending upon the material. The nutritive value of the food can also be affected seriously by the same agents. Thus, it has been reported (Lindemann 1953) that autoxidation and polymerization of fats in stored dried sorghum germ results in bleached fats of reduced iodine number. This is said not to occur with corn. In oats, poly-unsaturated fatty acids are said to produce bitter flavors on oxidation. Partial polymerization of these acids also takes place (Rothe 1953). In a more detailed study of the reaction (Rothe 1954), it is suggested that naturally occurring antioxidants react with fat peroxides. In this reaction the peroxide oxygen is transferred to the antioxidant and the fat is said to polymerize to a bitter substance. It is admitted that the function of peroxidase and lipoxidase in this reaction has not been established. In a third study (Thomas and Rothe 1954) of the problem of the role of lipase peroxidase and lipoxidase bacteria in the development of bitter flavors in cereals, it has

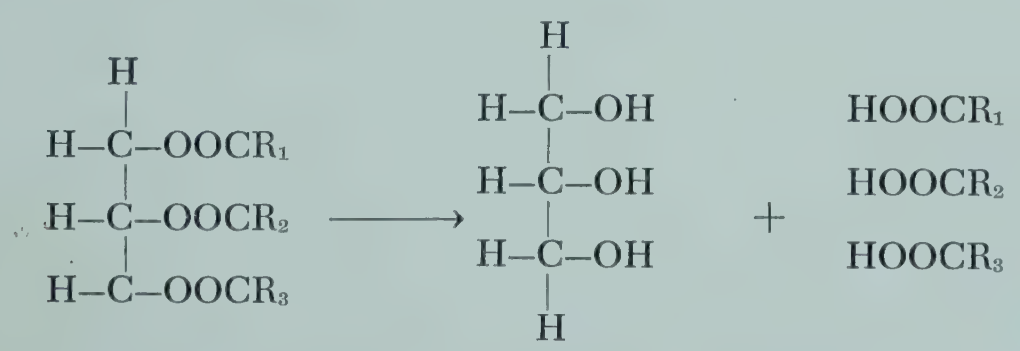
been established that only lipoxidase could be associated with flavor change.

With regard to the change in nutritive value of foods containing oxidized fats, the decoloration of carotene has already been discussed. The stability of vitamin A is open to question and vitamin E may be regarded as a naturally occurring antioxidant and therefore one of the first components of the food to be affected by the oxidized fats. The amino acid lysine is particularly susceptible to the presence of aldehyde groups, so that if the end products of fat oxidation gave rise to a significant quantity of aldehydes and ketones it is reasonable to suppose that the lysine content of the food will suffer.

In summary, it should be stated that the stability of a cereal or animal fat is not necessarily closely correlated with the stability of the final foods of which the cereal or shortening is a component. Storage tests on the finished product are necessary if a true measure of shelf life is to be obtained.

Mechanisms of Fat Hydrolysis

Considering now the hydrolysis of fat, this reaction can take place in the presence of moisture and enzymes with the result that the triglyceride is converted into glycerol and free fatty acids:



Fat splitting with moisture is employed by shortening manufacturers as a means of rearranging the distribution of fatty acids in a fat. The process requires the use of an excess of water or steam, high temperatures and pressures and often a catalyst.

The present discussion is more concerned with the splitting of glycerides in the presence of lipolytic enzymes. It is thought that the breakdown of the glyceride is a step wise process so that first the diglyceride is formed and then the monoglyceride. Finally, the fat is completely hydrolyzed into glycerol and fatty acids.

Lipases.—Although lipases are classed as non-specific esterases, it has been found that the speed of the reaction is affected by the molecular configuration of the substrate. In studies on pancreatic lipase the velocity of hydrolysis in a series of saturated fatty acids C_8 to C_{18} has been found to decrease with increased molecular weight (Ono 1940). This relation-

ship has not been found to hold with unsaturated fatty acids in the series C_{16} to C_{22} although at lower temperatures the velocity does seem to depend upon the number of double bonds. The effect of molecular configuration on water solubility must not be ruled out of these considerations. In a somewhat parallel situation it has been found that when attempts are made to measure lipase activity of cereal enzymes, lower amounts of cleavage are obtained when higher glycerides such as tripalmitin, tristearin and extracted wheat oil are used than when lower glycerides are employed as the substrate (Sullivan 1946.)

The degree of dispersion of the substrate is also an important factor. For this reason, and as will appear later, some methods for measuring lipase activity call for the use of finely dispersed emulsions of fat.

In common with all enzyme reactions, the rate of lipolysis of fat is strongly influenced by temperature. The optimum temperature has been reported as 100°F. Below 32°F. the activity of wheat germ lipase is inhibited (Singer and Hofstee 1948; Kühl 1940).

When measuring lipase activity of enzymes from different sources and for *in vitro* experiments in general, great care is taken to control the pH of the system. The true implication of this work, when applied to actual foodstuffs, is difficult to determine because in such a product as a prepared mix, pH is a local factor and can vary widely throughout the product. For experimental work a pH within the range 7.5 to 10 is usually employed.

The effect of moisture on *in vitro* systems is not important; whereas, in the case of cereals and foodstuffs, moisture is often of the utmost consequence. This point will be taken up again later on in the discussion.

Measures of Lipase Activity.—Many methods have been devised for measuring lipase activity of enzymes from a variety of sources. In research on cereals and legumes, lipase has received the most attention; whereas, in the medical field, pancreatic lipase was the object of initial interest in this area.

The original and standard method for assaying lipase was to allow the enzyme to react upon a standard oil substrate under standard conditions of time, temperature and pH. The fatty acids hydrolyzed from the fat were extracted from the reaction mixture using a solvent, and then titrated with alcoholic potash using phenolphthalein as an indicator. This method although simple in theory, was often difficult to carry out in practice if meaningful results were to be obtained. The purity of the substrate was critical, and the efficiency of the extraction process for the fatty acids limited the accuracy of the determination. The rate at which the liberated acids changed the pH of the system was important and a satisfactory and reproducible titration end-point was difficult to obtain.

Many other procedures have been devised for measuring lipase activity, but space permits few to be mentioned. Koch *et al.* (1954) have described a variation of the standard method using an electrometric titration procedure. The free fatty acids liberated from an emulsified reaction mixture buffered at pH 7.9 and held at 97°F. are determined by titration against standard alkali at 2- to 3-minute intervals. Koch found that the activity followed a zero-order reaction curve for reaction times between 10 and 60 minutes.

A manometric method has also been used for measuring wheat germ lipase activity (Singer and Hofstee 1948). A Warburg apparatus is employed, and the liberated fatty acids are allowed to react with sodium carbonate to produce carbon dioxide.

Hutchinson and Martin (1952) have described a method of measuring the lipolytic activities of cereal flours by incubating a mixture of the flour, water and olive oil under standard conditions, separating off the fatty acids and then measuring them in a routine manner. As a result of this work they suggested that any cereal flour, particularly oatmeal, which can hydrolyze 1.6 per cent of the olive oil in six hours should be regarded as undesirable.

A stalagmometric method depending on changes in oil surface tension has been described as a lipase assay procedure (Krijgsman 1928). A further physical method uses the Tyndall effect (Herzfeld 1934).

Recently Luchsinger *et al.* (1955) have made a fresh approach to the problem. Instead of measuring the amount of free fatty acids produced, these workers determined the quantity of glycerol released from a mono-olein emulsion at pH 7.4 and at 86°F. Using periodate cleavage, the glycerol was converted to formaldehyde which was reacted with chromotropic acid to give a colored complex. The absorption of this complex was measured at a wave length of 570 mμ.

Practical Importance of Fat Hydrolysis.—Having discussed briefly the more theoretical aspects of fat cleavage, it is interesting to examine the net effects which such a reaction may have on food stability and food acceptance.

In the case of wheat flour it has been reported that the maturing that occurs is connected with the production of fatty acids from the lipid fraction (fats and phosphatides) by the action of lipases (Dorner 1952). Other changes in the protein fraction do occur, however, which are not correlated with fat cleavage. During the maturing process, the color of the flour is improved probably due to oxidation of the color pigments. It has further been suggested (Mecham and Pence 1957) that to be effective in improving the baking quality of flour, the fatty acids liberated by lipolysis must undergo a degree of oxidation. There is also an ill-defined inter-

reaction of flour, fat, phosphatides, and protein which is affected by fat cleavage and oxidation. It is interesting to note that there is some evidence (Anon. 1950A) that changes taking place in wheat grain during storage do not parallel the changes occurring in wheat flour. In fact, it has been suggested that in the whole grain the lipases may synthesize fat rather than break it down. It has been reported that fatty acids have an effect on starch and wheat flour pastes as measured by the amylograph. The effect was modified by the quantity of fatty acid present and the length of the fatty acid chain (Mitchell and Zillmann 1951). Those results may presumably be interpreted as a partial explanation for the effect of fatty acids on the baking quality of flour. For a more detailed study of this field, Smith *et al.* (1957) have reported that the oxidation of polyunsaturated fatty acids in flour doughs runs counter to the effect of sulfur dioxide and sodium bisulfite on the mixing properties of doughs. The amount of oxygen used by the doughs is small in the absence of fatty acids, but even so, this has a marked effect on the physical properties and upon the dough sulfhydryl groups, but the two effects are not correlated with each other.

In an interesting study on the factors affecting wheat flour stability, Cuendet *et al.* (1954) stored various grades of white and whole wheat flour in sealed containers at moistures ranging from 3 to 14 per cent and held at a temperature of 37.8°F. He found that the more refined flours were the more stable and that chlorine dioxide treatment and moisture adversely affected stability. The increase in fat acidity was minimized with the most refined flours, was unaffected by chemical flour bleaching, and did not occur at the lowest moisture level of three per cent.

A report on the keeping quality of flour over prolonged storage periods has been given by Greer *et al.* (1954). Flours were stored in non-gas-tight tins for periods of up to 27 years. In the non-gas-tight tins, the flours were acceptable for 10 years. In the gas-tight tins it was found that the oxygen content of the head space gases decreased and the carbon dioxide content went up. Where the oxygen content was below five per cent the flour was unimpaired by storage and it is thought that this may have been the limit imposed by rancidity development. Generally, however, the fat in the flour was considerably hydrolyzed, the flour had an odor, and bread made from the flour was also odoriferous.

In passing, it is worth noting that a positive correlation has been reported between germ damage in sick wheat and fat acidity and that a fat acidity test has been proposed as an index of grain deterioration (Baker *et al.* 1957).

The situation in oat grains is somewhat similar. Although no evidence is available to indicate fat synthesis during grain storage, it is recorded

(Hutchinson *et al.* 1951) that under normal conditions of storage, namely 13 per cent moisture and a temperature of 64°F. fat acidity in oat grains increases quite slowly. If, however, the grain is crushed or milled, then there is a rapid increase in fat acidity from the normal free fatty acid content of 3 to 10 per cent. This change takes place within the first few days (Smith *et al.* 1957). It would seem that oat flour provides a good example of two processes producing an unpleasant deterioration—in fact, it has been suggested (Rothe 1956) that lipolysis and oxidation due to lipoxidase activity are responsible for the bitter taste which develops in oat products on storage.

Although much stress has been placed in the literature on the oxidation of the unsaturated fatty acids in corn and corn products, those workers familiar with these materials will have recognized the presence of lipase or esterase enzymes in these materials. These enzymes can impair quite noticeably the acceptability of foods containing corn through the development of high fat acidity followed by other changes detracting from the quality of the food. As to the location of the enzyme, little information is available, but it is a general opinion that the site is probably near the corn germ.

Rice lipase has been associated with the rice bran and enzyme activity may be increased by the presence of micro-organisms (Loeb and Mayne 1952) and moisture. It has further been reported that in rough rice, maintained at various moisture levels for seven months at 70°F. and 90°F., the amount of fatty acids increases logarithmically with time and approximately exponentially with moisture.

Turning now to breakfast cereals, only minor quantities of non-cereal materials are present, so that cereal stability largely determines product stability. The flake type breakfast cereal is made by flaking a cooked cereal particle in rolls. The stability of the product is affected not only by the type of cereal employed, but also by the processing conditions. In general the more severe the conditions the more stable the product. Rice flakes have the longest shelf life, followed by corn flakes, then wheat flakes, and finally oat flakes. The latter two materials have stabilities quite low in comparison with corn and rice flakes. Fat oxidation is thought to be the major factor in flavor deterioration of these products with fat cleavage as a possible secondary factor becoming more important in oat flakes. Expanded breakfast cereals follow the same pattern although with this type of food, puffed wheat, corn, and rice have an equivalent stability, but puffed oats are again much below the other three cereal products in shelf life.

Cereal flours are extensively used in prepared mixes such as pancake,

waffle, cake, muffin, corn bread, cookie, and doughnut mixes. The development of fat acidity due to enzymes in the cereal flours may have far reaching consequences.

If the cereal lipolytic enzyme is active, not only may the cereal lipids be split, but also some cleavage may occur in the shortening or fat which is an ingredient of the mix formulation. The presence of significant quantities of free fatty acids will impair the taste of the product since these compounds are often very flavorful.

Most of the prepared mixes are leavened chemically, in other words, they contain as ingredients quantities of a basic material such as sodium bicarbonate and an acid material such as monocalcium phosphate, sodium acid pyrophosphate or potassium bitartrate (cream of tartar). When the ingredients are mixed with water the reaction between the leavening components generates carbon dioxide which expands the structure of the cake; e.g.

$$\underset{\text{(monocalcium phosphate)}}{3CaH_4(PO_4)_2} + 8NaHCO_3 \longrightarrow Ca_3(PO_4)_2 + 4Na_2HPO_4 + 8CO_2 + 8H_2O$$

$$\underset{\text{(potassium bicitrate)}}{KHC_4H_4O_6} + NaHCO_3 \longrightarrow CO_2 + KNaC_4H_4O_6 + H_2O$$

In the formulation of the mixes the amount of acid leavening ingredient is carefully balanced against the basic leavening ingredient so that after the reaction has taken place the system will be at a suitable pH. Should there be an excess of acid ingredient a characteristic taste is imparted to the finished product. A different but also characteristic taste is noticeable in the product if the basic leavening ingredient is in excess.

If the production of fatty acids becomes excessive due to fat cleavage during the storage period of a mix, then it is not impossible for the free fatty acids to react with the basic component of the leavening system. This will result in some unneutralized acid component remaining in the baked product and this in turn will produce the undesirable taste.

The reaction of the fatty acid with the basic leavening component will result in the formation of an alkali ester of the acid of the type $R \cdot COONa$. This formula is typical of a soap and in fact a soapy taste is often the result of lipolysis in prepared mixes.

By contrast it might be mentioned that in some baked products (particularly in Europe) a slight soapy flavor is desirable. A product called "parkin" common to the north of England is not considered desirable until it has developed this characteristic. True shortbread from Scotland has a slight flavor of oxidized fat and soapy fat.

CONTROL MEASURES

Antioxidants

Having described the types of fats commonly found in foods, the types of reactions they undergo and the results that fat deterioration may have on food quality, it is appropriate to discuss those steps that may be taken to minimize these difficulties.

Dealing first with oxidative rancidity, the most common approach to control is through the use of antioxidants. The literature is replete with references to the effectiveness of various compounds in delaying oxidation of fats, but perhaps it is appropriate to begin the review of the subject by referring briefly to antioxidants which occur naturally in some food products.

Oat bran, it has been claimed, has antioxidant properties. Rice bran and rice bran extracts as antioxidants are the subject of several patents (Gyorgy 1947, Patterson and Williamson 1948). In one of these it is suggested that the extract is a crude vitamin B complex and this is combined with a sulfhydryl compound such as urea sulfanilamide, or sulfaguanidine to form a synergistic mixture capable of protecting animal and vegetable fats from oxidation. A second patent (Patterson and Williamson 1948) details a method for concentrating the rice bran antioxidant to give an enhanced protective effect. The basis of the method is an alcoholic precipitation of inert materials, followed by an ether extraction.

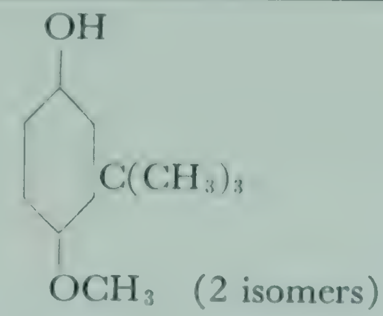
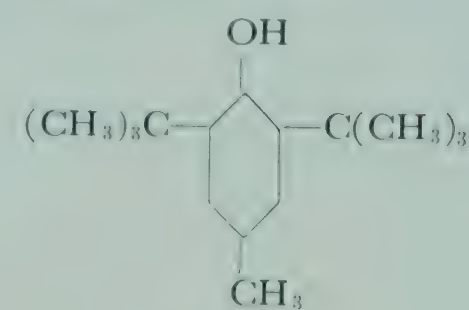
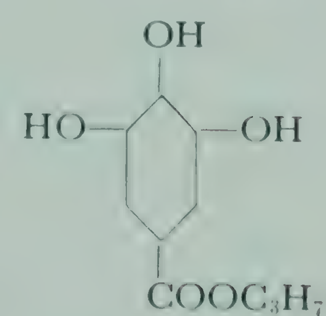
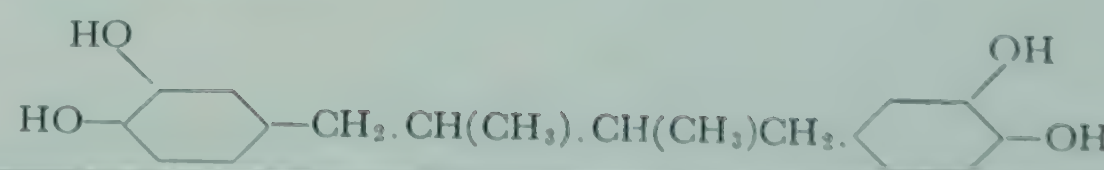
Wheat germ oil and soya lecithin are stated to be effective antioxidants for hydrogenated vegetable oil and butter (Dhar and Aggarival 1947), and in a further report (Lips 1952) the list of "natural" anti-oxidants is extended to include tocopherol, citric acid, and gum guaiac although it is pointed out that these materials are more effective in controlling rancidity than flavor reversion.

Considering now the use of synthetic anti-oxidants, one of the problems connected with the use of such materials has been the question of "carry through," that is the ability of the antioxidant to survive a baking or cooking process and so remain to protect the fat in the finished product. A further problem is concerned with the question of toxicity. Antioxidants may be regarded as food preservatives and as such are affected by legislation. Presently the four antioxidants shown in Table 124 are considered most suitable for use in stabilizing fats. These antioxidants are often used in synergistic mixtures with each other and other materials such as citric acid. In this way their effectiveness is substantially increased.

The present regulations (Anon. 1954) permit foodstuffs to contain BHA not more than one hundredth of one per cent, BHT, not more

TABLE 124

ANTIOXIDANTS USED IN FAT STABILIZATION

Chemical Name	Contraction	Formula
1. Butylated hydroxyanisole	BHA	
2. Butylated hydroxytoluene	BHT	
3. Propyl gallate	...	
4. Nordihydroguaiaretic acid	NDGA	

than one hundredth of one per cent, a combination of BHT and BHA of not more than two hundredths of one per cent, citric acid and/or phosphoric acid and/or mono-isopropyl citrate, not more than one hundredth of one per cent, either alone or in combination with BHA, BHT, or a combination of both. NDGA is allowed at the level of one hundredth of one per cent in lard and shortening but suffers from the disadvantage of not coming through the baking process particularly well.

There are several method used for the application of antioxidants to fats and products containing fats. The obvious, and original, method is to put a measured quantity into the liquid fat during processing. In the case of such materials as breakfast cereals and nuts, it is often convenient to spray the food with an oil solution of the antioxidant (Stuckey 1955). In processing of potato chips, the antioxidant may be put into the frying oil.

The incorporation of antioxidants into packaging material is also a measure which under certain circumstances can effectively prolong the shelf life of foods. It is logical to suppose that this method must in some way nullify the effect of heavy metals on fat which has seeped into the wraps as well as generally protecting the thin layer of fat which is in a most labile condition due to the large surface areas involved.

Hydrogenation

Hydrogenation is commonly used to reduce the degree of unsaturation of vegetable oils thus promoting the stability of these materials and the foods in which they are used. An index of the degree of unsaturation of a fat is the iodine value which is defined as the number of grams of iodine absorbed under standard conditions by 100 grams of fat. Bailey (1951) gave typical iodine values for baking fats which are collected in Table 125.

Hydrogenation is carried out by the fat manufacturers in large reactors, using a catalyst and hydrogen gas. From Table 125 it will be realized that animal fats are also often treated in this way. In that the hydrogenation of a fat also raises the melting point and changes the

TABLE 125

SOME TYPICAL IODINE VALUES FOR BAKING FATS

Fat	Iodine Value
All hydrogenated vegetable shortening	62
Compound-type shortening A	90
Compound-type shortening B	73
Prime steam lard	69
Prime steam lard with eight per cent hydrogenated lard steam added	65
Hydrogenated prime steam lard	61
All-hydrogenated vegetable shortening untempered	62

physical performance generally, there is a limit to the degree of hydrogenation that can be tolerated. A balance must be achieved between producing the desirable fat stability and maintaining optimum physical performance.

Other Means of Controlling Lipid Deterioration

Mention has already been made, during the discussion on the development of oxidative rancidity, that the degree of processing may have a noticeable effect on the rate at which the natural fat may go rancid. This effect is particularly noticeable during the preparation of such foods as breakfast cereal flakes and puffed goods. Although some of the fat deterioration is undoubtedly lipolytic in nature, it has been found that the more thorough processing does tend to lower the rate at which oxidation of the fat occurs. Naturally there is an upper limit to the processing that can be permitted. This limit is imposed by other types of heat damage that occur under extreme conditions.

The selection of ingredients is an obvious method of reducing oxidation in foodstuffs, particularly packaged mixes. Those items which tend to deteriorate readily under normal conditions of storage render the entire food unstable. Particularly is it important to insure that all source of contamination with heavy metals is avoided. In the writer's experience this is not an easy task since trace metals can be present in such items as coloring matters. Considerations of fortification often require the presence of significant amounts of iron. Although the flavor reversion of soya bean oil has never been linked specifically with oxidative rancidity it may be that a connection exists. For this reason soya bean oils were often looked on with disfavor. Now that modern technology has improved the quality of soya bean oil, reversion rarely takes place and compounded fats containing this type of oil are in common use.

Finally, in describing methods of reducing fat oxidation, the matter of packaging must be discussed. Vacuum or gas packaging in tin cans is perhaps the most perfect type of pack, but for consideration of space, weight, and economy, other materials must be used.

The employment of pliable films alone and in combination as laminates, has become increasingly popular, and today we have a choice of such material as cellophane, polyethylene, Polymylar, and Saran, to mention but a few. These synthetic polymers may be laminated to each other or to paper or aluminum foil to give practically any desired barrier against moisture, air, oxygen, or light. The sealing of these materials may be achieved by heat, by adhesives or by folding, depending upon the requirements of the product.

Many of the cereal flours and cereal products require but the simplest

of packaging material in that jute or linen bags or cardboard containers with or without waxed paper liners will suffice. The more complicated mixes and frozen cereal foods require wrapping materials of considerable complexity. In summary the saying may again be quoted that a food is no better than its packet.

Methods of reducing the effect of enzymes center around three objectives. These are inactivation of the enzyme by heat, reduction of enzyme activity by limitation of available moisture, and elimination of the enzyme source.

Considering first enzyme inactivation by heat, it has been found possible to inactivate lipase in wheat by warming for twenty minutes at 140°F. (Kretovitch *et al.* 1940) and a patent describes the combination of steam treatment followed by the sudden release of steam pressure as a means of promoting the keeping qualities of wheat, rice, barley, or oats (Huzenlaub and Rogers 1951).

A British paper (Hutchinson *et al.* 1951) reports that the lipolytic agent in oats may be destroyed by heating the oats or meal to 194 to 212°F. for a few minutes at a moisture content above twelve per cent and goes on to point out that the higher the moisture control in the range of 6 to 20 per cent the lower is the temperature required for enzyme inactivation.

A similar effect has been noted with corn where it has been possible to minimize the fat splitting ability of the naturally occurring enzymes by a suitable heat treatment under optimum conditions of moisture.

Turning to the reduction of enzyme activity by controlling moisture, the effectiveness of this method in reducing the fat splitting ability of flour was strikingly demonstrated by McWilliams and Soloski (1953). These workers made up yellow cake mixes from flour at 11.7, 8.0, 2.8 and 2.1 per cent moisture, using plastic shortening and two types of powdered shortening. The mixes were stored at 100°F. It was found that the cake mixes made with flour at 11.7 per cent moisture deteriorated at between 4 and 6 months and mixes made from flours with eight per cent moisture deteriorated at between 7 and 8 months. Mixes made with flours below 2.8 per cent moisture were stable for up to one year. Furthermore it was found that fat acidity development was less in mixes made from 8.0 per cent moisture flour than those made from 11.7 per cent moisture flour. At the same time there was no fat acidity development in mixes made from flour at 2.8 per cent moisture and below. Finally there was found to be no correlation between peroxide values, that is fat oxidation, and storage deterioration.

It is hardly necessary to mention again the importance of correct milling processing in minimizing the effect of enzymes by elimination of the enzyme source. Thus it has been found that the degerming process for

corn meal does much to enhance the stability of the product (although detracting somewhat from the flavor) by limiting the speed with which fat acidity develops. With lipoxidase, it has been found that the high grades of flour show relatively a greater stability than the lower grades. With oats, a wet dehulled oat shows a markedly reduced lipase activity.

In addition to the selection of the quality of ingredients, it is possible as mentioned in dealing with oxidative deterioration of fats, to influence product stability by the type of ingredients used so that the pH, moisture and substrate are as far as possible from that required for optimum enzyme activity.

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CHAPTER 23

Charles Feldberg

Adequacy of Processed Cereals in Human Nutrition

INTRODUCTION

From earliest recorded times until the present, cereal foods have supplied a significant proportion of the nutrients eaten to maintain health and well-being. There has been a close relationship between the advance of agriculture and the growth of civilization. When men first learned to plant crops they, of necessity, had to remain in one place long enough to harvest these crops. Since the land had already been cleared and cultivated once, it became easier to replant it for the next season than to move and start all over again. Thus, as more families gathered in one favorable locale, villages grew up and men learned to live together for mutual benefit and protection.

Our civilization now has developed to the point where in the United States the available food supply continues to be abundant, and if it were distributed according to nutritional needs, every single person in our population group would be well fed. In actual practice, recent dietary surveys indicate that because of individual food preferences, income level and lack of nutritional knowledge, many persons in our population subsist on diets that provide less than the National Research Council's Recommended Dietary Allowances for certain nutrients. Prominent among the nutrients which are in short supply are protein, minerals such as calcium and iron, and vitamins such as thiamin and riboflavin. These figures are based on the amount of food available and not on actual food intake. Therefore, such factors as plate waste, processing and cooking losses have not been taken into account. If they had been, the numbers of individuals subsisting on diets low or marginal in the various nutrients would be higher.

The enrichment of bread and other grain products with vitamins and iron has been instrumental in improving the nutritional adequacy of our diet. However, as mentioned above, many individuals are still receiving suboptimal diets. Cereal foods are generally considered to be economical sources of calories, protein and of some vitamins and minerals. For instance, one-fourth pound of enriched bread supplies approximately 17 per cent of the daily allowance of thiamin for adult males as recommended

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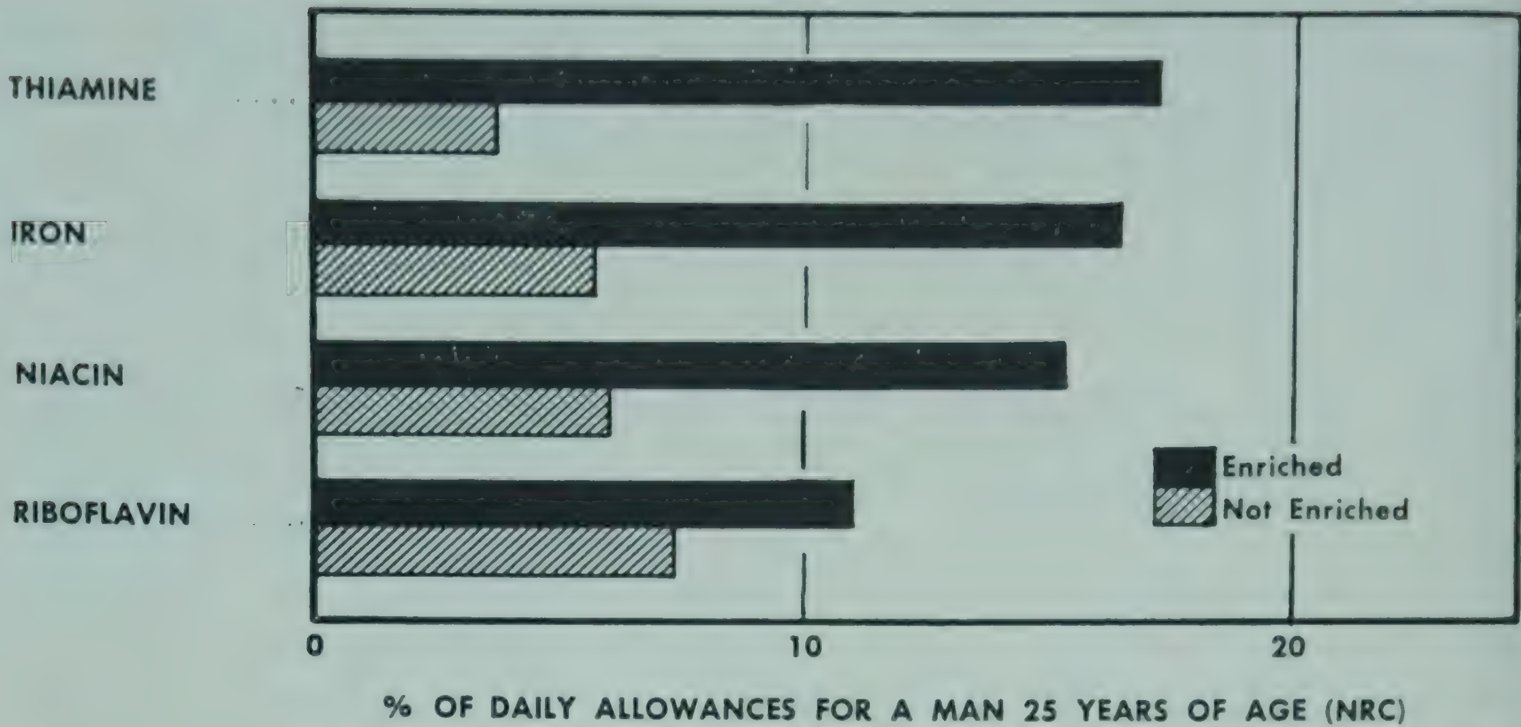


FIG. 156. NUTRITIONAL CONTRIBUTION OF ONE-FOURTH POUND ENRICHED AND UNENRICHED BREAD

Approximately 5 slices of bread 1/2 inch thick weighing 23 grams each.

by the U. S. National Research Council (Fig. 156). Similarly, this amount of bread supplies significant levels of other essential nutrients. On the other hand, bread and most cereal products are lacking or deficient in certain essential nutrients, such as vitamin B_6. Also, the protein quality in most cereals is inferior to that of high-quality animal protein foods.

In this chapter, the nutritive value of processed cereals will be discussed. This will include a review of the nutrients in food—protein, carbohydrate, fat, vitamins and minerals. Since the functions of food are to build body tissue, to regulate body processes and to supply energy, the roles of the various nutrients in these functions will be discussed. Finally, the effects of commercial processing on these nutrients in cereal products, and how various nutritional deficiencies in these cereals have been, and might be, improved will be considered.

PROTEIN AND AMINO ACIDS

During recent years medical and nutrition researchers have defined the vital importance of adequate protein nutrition in promoting optimum growth, muscular development and resistance to disease in children; in diminishing the incidence of toxemias and premature deliveries in pregnancy; and in maintaining the integrity and health of body tissues into old age. Protein-deficiency conditions occur among virtually entire populations in many parts of the world and among appreciable portions of

the populations even in relatively well-nourished countries such as the United States.

Proteins, carbohydrates and fats are familiar terms, in which most people will recognize the three fundamental classes of human and animal nutrients. Of the three, however, protein is by far the most important. In contrast, carbohydrates and fats are primarily fuels which are either burned at once by the body or sent into storage. Protein, on the other hand, is a class of chemical compound from which living tissue is built; its very name derives from the Greek word for "first."

Proteins are almost incrediably complex compounds, and the number of different kinds of proteins which are chemically possible is unlimited. In the human body, there are at least 35 proteins in the blood plasma alone, and probably hundreds of thousands in the other body fluids and tissues.

TABLE 126

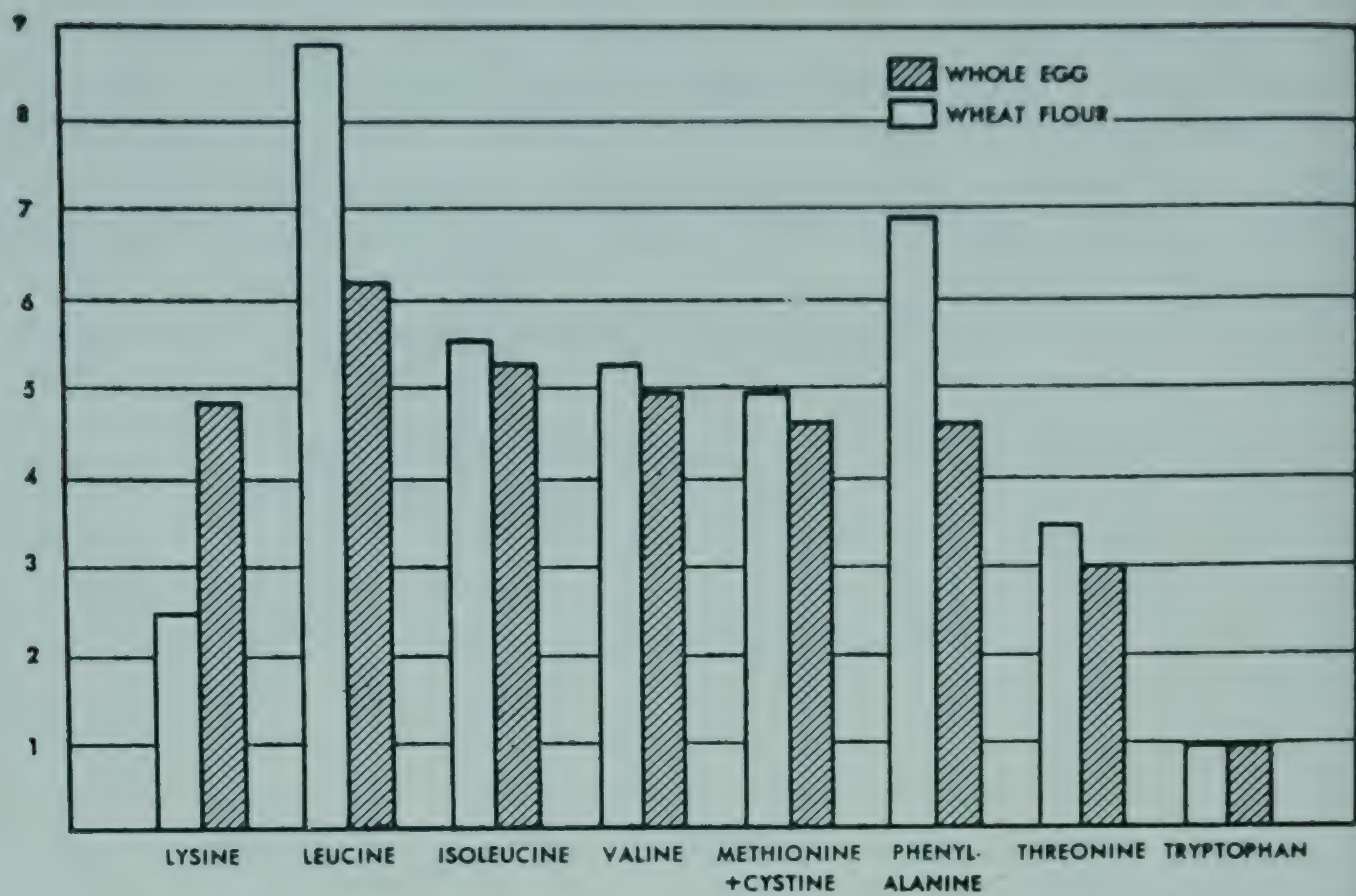
AMINO ACIDS IN HUMAN NUTRITION

Essential	*Non-essential*
Lysine	Arginine
Methionine	Histidine
Leucine	Aspartic acid
Isoleucine	Glutamic acid
Threonine	Alanine
Valine	Glycine
Phenylalanine	Proline
Tryptophan	Hydroxyproline
	Tyrosine
	Cystine
	Serine
	Citrulline

This breakdown and regeneration of body proteins is made possible, despite their enormous complexity, by the fact that all proteins are assembled from the same comparatively simple set of building blocks. These blocks are the amino acids, of which there are approximately 22. Not all 22 may occur in a given protein; for example, insulin is a relatively uncomplicated protein made up of 15 amino acids. However, most proteins are much more complex than this.

The rate of breakdown of proteins in the human body make it urgent that they be replaced on a continuous basis, either in the diet or by synthesis in the body.

Man can manufacture only a portion of his amino acid requirements. Those which he cannot synthesize in adequate amounts and which consequently must be supplied preformed in the diet, have been termed "essential." Conversely amino acids which can be synthesized adequately



Based on data from Block and Bolling (1951)

FIG. 157. AMINO ACID PROPORTIONS IN WHEAT FLOUR PROTEIN AND IN WHOLE EGG PROTEIN

Based on tryptophan as unity. Part of the requirement for methionine can be supplied by cystine.

by the body have been classified "non-essential." Eight amino acids are considered to be essential to human nutrition. These eight essential amino acids and twelve of the most common non-essential amino acids are listed in Table 126.

All of these amino acids, essential and non-essential, are used by the body to build tissue.

Only the L-isomers of the essential amino acids are utilized, with the exceptions of D-methionine which is fully as active as the L-isomer, and of D-phenylalanine, which is active but to a lesser degree than the L-isomer.

Amino Acid Balance

Dietary proteins constitute man's principal source of nitrogen. The proteins in foods from plant and animal sources, however, differ quantitatively in amino acid composition. The proteins of meat, eggs, fish and milk have high nutritional value because they contain a good balance of amino acids which resembles that required by body tissues. Cereal proteins, on the other hand, such as those in wheat flour, rice and corn meal

are unbalanced in terms of essential amino acids. The most deficient amino acid in wheat proteins is lysine. Fig. 157 shows that in comparison with whole egg protein, wheat flour is deficient in lysine. Similarly, it has been shown that corn is deficient in lysine and tryptophan; rice is deficient in lysine and probably threonine.

The synthesis and destruction of protein in the body tissues is a continuous and dynamic process. The need for amino acids is particularly high during periods of growth, reproduction and lactation, although the requirements for maintenance and repair are incessant.

During the replacement of tissue proteins there is considerable destruction of amino acids. These must be obtained from the diet or be synthesized in the body from other dietary components. If the diet is deficient in amino acids, especially in essential amino acids or in starting materials for synthesis of non-essential amino acids, the building and repair of body tissues is retarded until these deficiencies are supplied in the diet. In short, the correct balance of amino acids in the diet is just as important as the total amount of protein.

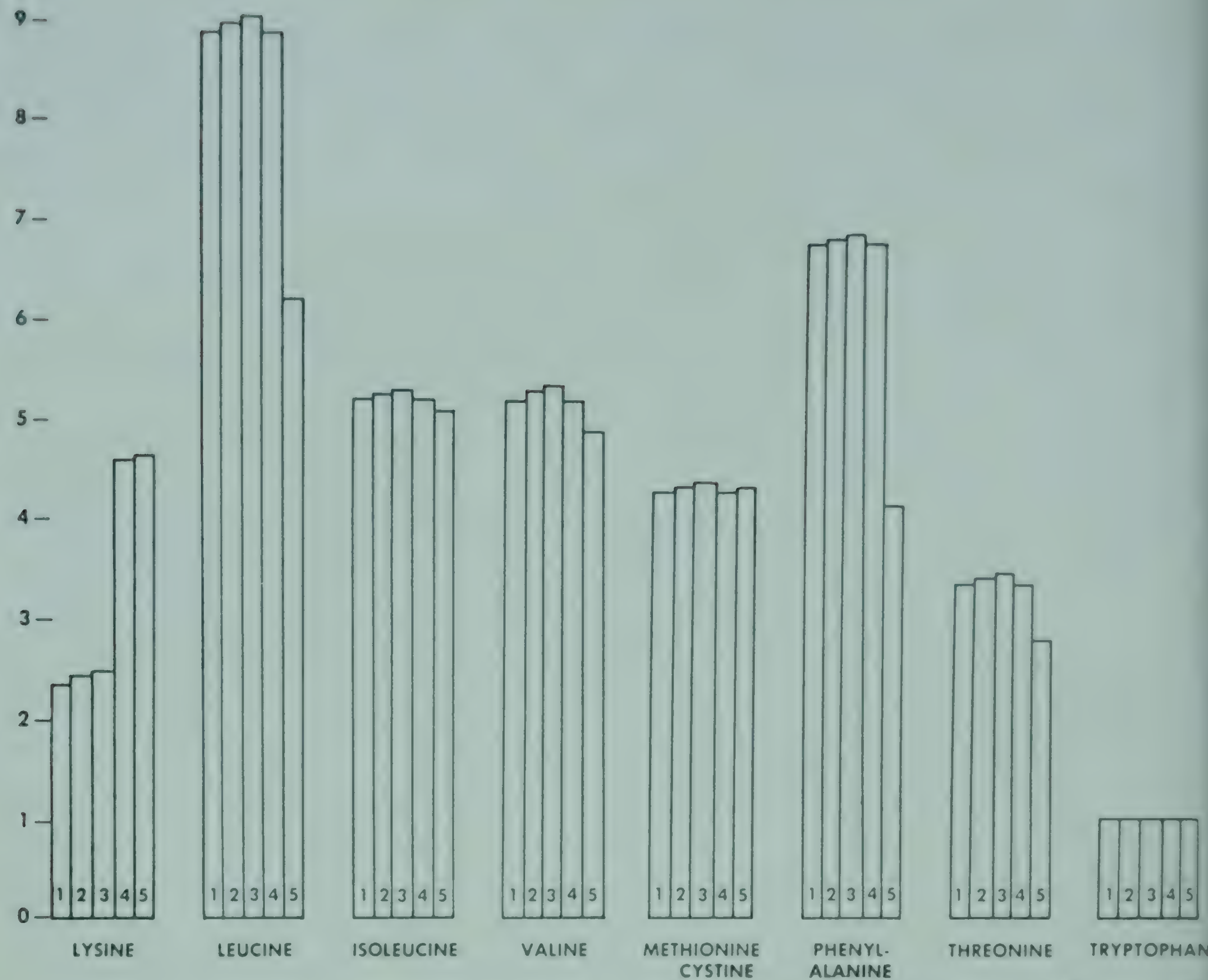
Also, it is important to provide all the essential amino acids in the diet at the same time, to receive the most benefit from food proteins. Animal feeding studies of amino acid mixtures showed that full production of tissue proteins occurred only when all the essential amino acids were supplied simultaneously in the right proportions. A time interval greater than one hour between the ingestion of an incomplete amino acid mixture and its supplemental missing amino acid resulted in decreased growth rate (Geiger 1947, Cannon *et al.* 1947, Henderson and Harris 1949).

It has been shown that the nutritive value of proteins is primarily dependent on their amino acid balance. By the proper combination of available protein and by small additions of supplementary amino acids to staple foods, it now appears possible to effect the equivalent of a 50 to 100 per cent increase in dietary protein without increasing the amount of food grown. When the nutritional value of a food protein is limited by a deficiency of one of the essential amino acids, the addition of a small amount of this limiting amino acid gives a relatively large increase in biological value of that food protein.

Amino Acid Fortification of Cereals

Cereal proteins, such as those in wheat flour, rice and corn meal, are considered to be "low-quality" proteins since they are either lacking or deficient in one or more of the essential amino acids. In cereal proteins the limiting amino acid is usually lysine. This deficiency of amino acids limits the use of the protein in cereal products by the body.

Quantitatively, the amount of protein in cereals varies from approxi-



From Wrenshall and Feldberg (1958)

FIG. 158. AMINO ACID PROPORTIONS IN WHEAT FLOUR PROTEIN, WITH AND WITHOUT ADDED NON-FAT MILK SOLIDS AND LYSINE, AND IN EGG PROTEIN

Based on tryptophan as unity.
1—White Flour Protein; 2—White Flour Protein + 3 per cent NFMS; 3—White Flour Protein + 6 per cent NFMS; 4—White Flour Protein + 0.25 per cent L-Lysine Monohydrochloride; 5—Egg Protein.

mately 25.2 per cent in wheat germ down to 5.9 per cent in a puffed rice breakfast cereal (Table 127). The biological value of cereal proteins—that is the per cent of absorbed nitrogen retained for growth and maintenance—is considerably inferior to that of high-quality animal proteins. This indicates that cereal proteins are only partially available to the body for tissue maintenance and growth. That portion of protein not used by the body for tissue synthesis is converted to energy, that is, burned as fuel similar to fat and carbohydrate.

Wheat-Based Products

It has been known for many years that wheat protein is deficient in lysine. White flour prepared by modern milling procedures is even more deficient in this amino acid. By adding to flour up to six per cent non-fat

TABLE 127[1]

COMPOSITION OF CERTAIN CEREAL FOODS, 100 GRAMS EDIBLE PORTION

Food	Water Per cent	Food Energy Calories	Protein Gm.	Fat Gm.	Carbohydrate Gm.	Ash Gm.	Calcium Mg.	Phosphorus Mg.	Iron Mg.	Vitamin A U.S.P. units	Thiamin Mg.	Riboflavin Mg.	Niacin, Mg.	Vitamin C Mg.
Barley, pearled, light, dry	11.1	349	8.2	1.0	78.8	0.9	16	189	2.0	0	0.12	0.08	3.1	0
Bran flakes (40% bran)	3.6	292	10.8	1.9	78.8	4.9	61	622	5.1	0	0.46	0.23	8.7	0
Bread, rye	35.3	244	9.1	1.2	52.4	2.0	72	147	1.6	0	0.18	0.08	1.5	0
Bread, white, unenriched, 4% non-fat milk solids	34.7	275	8.5	3.2	51.8	1.8	79	92	0.6	0	0.05	0.11	0.9	0
Bread, white, enriched,[2] 4% non-fat milk solids	34.7	275	8.5	3.2	51.8	1.8	79	92	1.8	0	0.24	0.15	2.2	0
Bread, whole wheat	36.6	240	9.3	2.6	49.0	2.5	96	263	2.2	0	0.30	0.13	3.0	0
Corn, sweet, raw yellow	73.9	92	3.7	1.2	20.5	0.7	9	120	0.5	390	0.15	0.12	1.7	12
Corn flakes	3.6	385	8.1	0.4	85.0	2.9	11	58	1.3	0	0.04	0.10	1.6	0
Corn grits, degermed, unenriched, dry	12.0	362	8.7	0.8	78.1	0.4	4	73	1.0	300[3]	0.13	0.04	1.2	0
Corn grits, degermed, enriched,[2] dry	12.0	362	8.7	0.8	78.1	0.4	4	73	2.9	300[3]	0.44	0.26	3.5	0
Corn meal, degermed, unenriched, dry	12.0	363	7.9	1.2	78.4	0.5	6	99	1.1	300[4]	0.14	0.05	1.0	0
Corn meal, degermed, enriched,[2] dry	12.0	363	7.9	1.2	78.4	0.5	6	99	2.9	300[4]	0.44	0.26	3.5	0
Farina, unenriched, raw	10.5	370	10.9	0.8	77.4	0.4	28	112	1.0	0	0.06	0.06	0.8	0
Farina, enriched,[2] raw	10.5	370	10.9	0.8	77.4	0.4	28	112	1.3	0	0.37	0.26	1.3	0
Macaroni, unenriched, dry	8.6	377	12.8	1.4	76.5	0.7	22	165	1.5	0	0.09	0.06	2.0	0
Macaroni, enriched,[2] dry	8.6	377	12.8	1.4	76.5	0.7	22	165	2.9	0	0.88	0.37	6.0	0
Oatmeal, dry	8.3	390	14.2	7.4	68.2	1.9	53	405	4.5	0	0.60	0.14	1.0	0
Rice, brown, raw	12.0	360	7.5	1.7	77.7	1.1	39	303	2.0	0	0.32	0.05	4.6	0
Rice, white, raw	12.3	362	7.6	0.3	79.4	0.4	24	136	0.8	0	0.07	0.03	1.6	0
Rice, flakes	3.5	392	5.9	0.6	87.7	2.3	21	116	1.8	0	0.08	0.08	0.9	0
Rice, puffed	3.5	392	5.9	0.6	87.7	2.3	21	116	1.8	0	0.08	0.08	0.9	0
Rye flour, light	11.0	356	9.4	1.0	77.9	0.7	22	185	1.1	0	0.15	0.07	0.6	0
Rye flour, dark	11.0	318	16.3	2.6	68.1	2.0	54	536	4.5	0	0.61	0.22	2.7	0
Wheat flour, whole (from hard wheats)	12.0	333	13.3	2.0	71.0	1.7	41	372	3.3	0	0.55	0.12	4.3	0
Wheat flour, 80% extraction (from hard wheat)	12.0	365	12.0	1.3	74.1	0.65	24	191	1.3	0	0.26	0.07	2.0	0
Wheat flour, self-rising, unenriched	12.0	350	9.2	1.0	73.8	4.0	272	484	1.0	0	0.08	0.05	1.1	0
Wheat flour, self-rising, enriched[2]	12.0	350	9.2	1.0	73.8	4.0	272	484	2.9	0	0.44	0.26	3.5	0
Wheat flour, patent, all purpose, unenriched	12.0	364	10.5	1.0	76.1	0.43	16	87	0.8	0	0.06	0.05	0.9	0
Wheat flour, patent, all purpose, enriched[2]	12.0	364	10.5	1.0	76.1	0.43	16	87	2.9	0	0.44	0.26	3.5	0
Wheat flour, bread, unenriched	12.0	365	11.8	1.1	74.7	0.44	16	95	0.9	0	0.08	0.06	1.0	0
Wheat flour, bread, enriched[2]	12.0	365	11.8	1.1	74.7	0.44	16	95	2.9	0	0.44	0.26	3.5	0
Wheat flakes	3.8	355	10.8	1.6	80.2	3.6	46	329	3.0	0	0.08	0.18	4.8	0
Wheat germ	11.0	361	25.2	10.0	49.5	4.3	84	1,096	8.1	0	2.05	0.80	4.6	0
Wheat, rolled, dry	10.1	340	9.9	2.0	76.2	1.8	36	342	3.2	0	0.36	0.12	4.1	0
Wheat, shredded, plain	5.6	360	10.1	2.5	80.1	1.7	47	360	3.5	0	0.22	0.12	4.4	0

[1] Adapted from Anon. (1950).
[2] Enriched to minimum levels specified in Standards of Identity.
[3] Yellow corn grits.
[4] Yellow corn meal.

milk solids, the American baker succeeds in raising the lysine content of bread. Actually, based on flour weight the average amount of milk solids used is between 3 and 4 per cent (Kulp *et al.* 1956). Even a six per cent addition of milk solids, however, does not supply enough lysine to overcome the low level in bread protein (Fig. 158).

Weanling rats fed a dried bread diet containing three parts non-fat milk solids per 100 parts of flour and supplemented with fat, salts and vitamins, showed a 75 per cent improvement in weight gain when 0.2 per cent of L-lysine was added to the diet (Rosenberg and Rhodenburg 1952). In another study, it was shown that as far as growth in weanling rats is concerned lysine is the only amino acid deficiency in commercial white bread. Further supplementation with valine, threonine or methionine was without effect (Rosenberg *et al.* 1954).

A similar experiment was conducted in which the bread ration did not contain the three parts of non-fat milk solids. In these studies the optimum growth response was obtained with an addition of 0.25 per cent of L-lysine. Since three parts of non-fat milk solids contain 0.082 per cent of lysine, these results can be closely correlated with those of the previous study (Hutchinson *et al.* 1956).

Similar studies by other investigators have indicated that the protein quality of commercial white bread can be substantially improved by the addition of small quantities of L-lysine (Hutchinson *et al.* 1956A, Jahnke and Schuck 1957).

Since these studies were carried out with weanling rats, these data must be related to human requirements. Although there are certain drawbacks in applying experimental results with rats to human needs, many of today's accepted allowances of essential nutrients for humans were derived from studies in genetically selected rat colonies. There is evidence that this may also be true for the amino acid requirements of humans. The proportionate requirements of the essential amino acids for the maintenance of nitrogen equilibrium in man approximate those of growing animals for maximum nitrogen retention (Mitchell 1954). Table 128 shows that for various proteins adult man resembles the growing rat more closely than he does the adult rat in his metabolic utilization of food proteins. Hegstead (1957) noted that the rat apparently has slightly different amino acid needs from man because a greater proportion of the protein is required by rats for the growth of hair. These variations are minor, and the data on the biological value of proteins obtained with rats are considered essentially applicable to man.

In addition, many authorities (Howard *et al.* 1958, Block 1956, Allison 1957) believe that for man a complete protein should contain 5.3 gm. of L-lysine per 100 gm. of protein. Albanese (1955) stated that the lysine-

TABLE 128[1]

BIOLOGICAL VALUES OF PROTEIN

Protein Source	Growing Rat	Adult Rat	Adult Man
Egg albumin	97	94	91
Whole egg	87	82	94
Wheat gluten	40	65	42
Casein	69	51	68
Peanut flour	54	46	56
White flour	52	65	41

[1] Adapted from Mitchell (1954).

to-tryptophan ratio (L/T) should be at least 5.6 and since tryptophan is usually one per cent or less in food proteins these figures are in general agreement. The L/T ratio of human muscle is approximately 5.6 to 1. Commercial white bread supplemented with three parts of non-fat milk solids has an L/T ratio of 2.6/1 and, therefore, contains a suboptimal amount of L-lysine. Block and Bolling (1945) stated that the daily requirement for lysine in humans should approach 5.2 grams. To supply this need, it would take 186 grams of protein derived from white bread supplemented with 6 per cent non-fat milk solids, or 260 grams of protein derived from white bread containing 3 per cent of non-fat milk solids. On the other hand, it would require only 108 grams of protein derived from white bread supplemented with 0.2 per cent L-lysine to supply this need.

Since we are mainly concerned with the nutritive value of wheat protein for humans, the correlation of rat feeding data with those of human studies must be considered. The addition of lysine alone to wheat gluten (the major protein of white flour) has been demonstrated to raise its protein efficiency into the animal protein range for both infants and adults.

Hoffman and McNeil (1949) found that the addition of 4 per cent lysine to wheat gluten increased the nutritive value of the protein, as measured by nitrogen balance in human adults, and it approached the value for casein. These workers concluded that lysine improves the nutritive value of gluten for humans as it has been shown to do for lower animals.

Bricker *et al.* (1945) fed enriched white flour to adult humans as the sole source of protein. While on this white flour diet for five days a female subject, age 23, was in a state of negative nitrogen balance. For the next five days, she consumed essentially the same diet plus a daily supplement of lysine providing 0.263 grams of nitrogen. Immediately, the urinary nitrogen level dropped and the subject went into positive balance indicating the benefits of lysine supplementation in humans.

Albanese *et al.* (1955A) studying infants, found that the nutritive value of the protein in infants' cereal foods including milk could in many cases be improved by the addition of small quantities of lysine. Loughlin and Wetzel (1957) in a recent study of malnutrition in the tropics found that the addition of one gram of L-lysine daily to the diets of Haitian children, subsisting mainly on a cereal diet, resulted in greater improvements in height and weight than in children receiving no lysine supplement.

In comparing the protein quality and quantity of white bread and protein bread to that of egg, Stare (1957) stated that three slices of ordinary white bread equal the protein of one egg in terms of total quantity of protein. However, the quality of the bread protein is only about a third that of egg. Therefore, nine slices of ordinary white bread are required to equal one egg in terms of quality of protein. If white bread is supplemented with lysine, only five slices will equal one egg.

In a similar manner protein breads, which have become increasingly popular, can be improved by lysine supplementation. A quantity of protein equivalent to one egg is supplied by two slices of a typical protein bread, but a correction for quality requires about five slices. If the protein bread is supplemented with lysine, only three and one-half slices will provide the same protein quantity and quality as one egg. On this basis, lysine-supplemented protein bread has a protein efficiency two and one-half times that of non-supplemented white bread.

Thus, through the judicious lysine supplementation of wheat protein it has been demonstrated that its quality and efficiency can be markedly improved.

The protein quality of other wheat-based foods, such as macaroni, farina products and wheat flakes cereal, can be markedly improved by the addition of approximately 0.2 per cent L-lysine based on the weight of the product. As in the results reported for bread, the addition of L-lysine monohydrochloride to macaroni and farina products results in an improvement in protein efficiency of approximately two times. Wheat flakes cereal which has a protein efficiency rating of zero also improved but not to the same extent as other food products (Anon. 1958).

The addition of approximately 0.2 per cent L-lysine to macaroni and wheat flakes cereal improves the protein efficiency ratios of the products to the same level as that of macaroni and wheat flakes cereal in the presence of low amounts of milk. In those mixtures with low milk about 30 to 35 per cent of the total protein of the mixture was derived from milk and about 65 to 70 per cent from wheat protein. The protein quality of these mixtures having a low proportion of milk can be improved further by the addition of L-lysine. The protein efficiency ratio of wheat flakes cereal in the presence of low amounts of milk plus 0.2 per cent

added L-lysine is 2.3 and for macaroni in the presence of low milk plus 0.2 per cent L-lysine is 2.5. This is about equivalent to the protein efficiency ratio of a food combination in which wheat protein and milk protein make up equal proportions of the mixture. When the ratio of milk protein to wheat protein is about 50:50, the addition of L-lysine gives no significant improvement in protein quality.

To obtain high-quality protein, bread should contain 44 per cent L-lysine as a percentage of the protein after baking. Since there is approximately a 10 to 20 per cent loss of L-lysine in baking, about 5.5 per cent L-lysine should be present in the dough protein before baking. On this basis other supplements may be used to improve the lysine level in bread. Lactalbumin containing approximately 10.5 per cent lysine or non-fat milk solids with about 8 per cent may be used to improve the protein quality of bread and of other wheat-based products. About 10 to 11 per cent lactalbumin based on the weight of the flour or 36 per cent non-fat milk solids must be used (Anon. 1958). Other products which may be used to improve protein quality are soybean protein and casein. However, impractical high levels of these additives would be necessary. On a weight basis L-lysine monohydrochloride is the supplement of choice (Howard *et al.* 1958). It is possible that a combination of one or more of these supplementary proteins plus lysine may be a practical means of improving both protein quality and quantity.

Some products already on the market are being fortified with L-lysine monohydrochloride. These include protein breads, cookies and various ready-to-serve cooked cereals for infants.

Rice-Based Products

Rice contains proteins which are deficient in certain of the essential amino acids. The addition of amino acids to improve the quality of rice protein has been studied by many investigators. It is not yet clear whether the addition of lysine alone or in combination with threonine will afford the optimum improvement in the quality of rice.

The protein in polished rice can be improved by supplementation with 0.2 per cent L-lysine and 0.12 per cent L-threonine. Diets supplemented at these levels produce a growth response in rats three times greater than in rats on an unsupplemented rice diet (Pecora and Hundley 1951).

The protein quality of rice bran and rice polish used in livestock feeding can be improved by the addition of 0.2 per cent L-lysine, 0.2 per cent DL-threonine and 0.1 mcg. of vitamin B_{12}.

Nitrogen balance in adults was used to evaluate certain amino acids as supplements to rice diets (Hundley *et al.* 1957). The authors concluded that in these diets there was a need for more nitrogen from essential

or non-essential amino acid sources. Lysine, alone, seemed to produce an improved nitrogen balance in some subjects over and above that which could be explained by a contribution of nitrogen alone. Threonine did not show a similar effect and the authors stated that the human adult is clearly unlike the growing rat which needs both lysine and threonine for improved utilization of rice protein.

In a more recent study (Rosenberg and Culik 1957) the nutritive value of the protein in white polished rice was improved by additions of small amounts of L-lysine alone. The addition of 0.05 to 0.10 per cent of L-lysine monohydrochloride to a 90 per cent precooked white polished rice diet significantly improved the growth rate and food utilization of weanling rats.

These studies indicate that it may be possible to improve the protein quality of rice by the addition of low levels of certain amino acids. Since rice provides a major portion of the nutrients ingested by a wide segment of the world's population an improvement in the protein of rice would benefit a great number of people.

Rye Products

The addition of lysine alone or threonine alone to a rye flour containing eight per cent protein produced very little improvement in growth in rats. However, the addition of a combination of 0.25 per cent L-lysine and 0.2 per cent threonine to this diet yielded a significant increase in growth and protein efficiency (Sure 1954). Stromnaes and Kennedy (1957) reported that the addition of lysine alone significantly improved the protein efficiency of rye bread in rat growth studies. The protein quality of rye bread and of the unbaked ingredients supplemented with 5 per cent non-fat milk solids or 0.166 per cent L-lysine was determined. The supplement of milk solids increased the protein efficiency ratio 9 per cent for the bread and 11 per cent for the unbaked ingredients.

Corn-Based Products

Available evidence indicates that corn protein is naturally deficient in both lysine and tryptophan. Commercial processing of corn results in some destruction of the natural L-tryptophan as well as L-lysine. This would serve to increase the need for amino acid fortification.

It has been reported that when milled corn was the sole protein in the diets of rats the addition of either L-lysine or L-tryptophan alone improved the biological value of the protein. However, the addition of 0.2 per cent L-lysine and 0.1 per cent L-tryptophan together, based on the weight of the milled corn, was accompanied by a 124 per cent increase in body weight and a 73.5 per cent increase in protein efficiency. These

results indicate that both lysine and tryptophan are equally limiting amino acids in corn (Sure 1948). In whole yellow corn the addition of 1.0 per cent DL-lysine together with 0.5 per cent DL-tryptophan produced an increase in growth of 138 per cent and an increase in protein efficiency of 66 per cent as measured in rats. These results were markedly better than when lysine alone was the supplement (Sure 1953).

Breakfast Cereals

The grains from which breakfast cereals are produced are naturally deficient in one or more of the essential amino acids, mainly lysine. In addition, the destruction of or formation of non-utilizable configurations of essential amino acids during processing increases the need for supplements of amino acids.

The nutritional value of various commercial cereal breakfast foods was evaluated by using the rat growth method to determine protein efficiency ratios of the products. Of 15 cereals tested only four were considered adequate in regard to protein efficiency. These cereals alone were of exceptionally poor protein quality, although when fed with enough milk the resulting mixtures may have supported growth (Sure 1951). However, milk protein is well balanced in essential amino acids and when it is used to improve the lysine content of cereals, the resulting protein mixture is inferior to milk protein in lysine content, and amino acids other than lysine are present in excess. These amino acids will not be used in tissue synthesis. Also, it is not possible to raise the amino acid content of cereal proteins to animal protein levels by mixing cereal proteins in the diet. Sure (1957) evaluated various mixed cereals and found that an addition of 0.2 per cent L-lysine improved the protein efficiency in a mixed cereal of oatmeal and barley. Additional improvement was noted with supplements of vitamin B_{12}.

Another reason for amino acid fortification of breakfast cereals is that the lysine and, in some cases, the tryptophan value of ready-to-eat whole wheat, corn, oat and rice breakfast foods is much less than whole grains.

Any supplementation of foods with the most limiting amino acid, the addition of which will improve the natural amino acid pattern, should be considered as sound nutritional practice and is to be encouraged. This is especially true of cereal foods which are deficient in certain of the essential amino acids.

CARBOHYDRATE

Carbohydrates are nutrients which provide the body with energy. In certain instances carbohydrates may be converted into fat and then stored by the body in this form.

In the United States, up to 50 per cent of the calories in the diet are derived from carbohydrates. This is due to the fact that foods which contain large amounts of carbohydrates are usually relatively inexpensive and are traditionally the major components of the diet. Cereals, fruits and vegetables contain high levels of carbohydrates, while meat, fish and dairy products are usually poor sources.

Three major classifications of carbohydrates are sugar, starch and cellulose. Since all types of carbohydrates which are absorbed by the body are used to provide energy or are converted to fat, it is customary to consider the total amount of carbohydrate available to the body rather than the amounts of the various types available.

Although carbohydrate is the main fuel source of the body, it is stored in the body in only small amounts and must be ingested or made as needed. The tissues of the body use carbohydrate under all physiological conditions resulting in a constant requirement for this nutrient. If sufficiently large amounts of carbohydrate are not regularly present in the diet, the need for this compound must be met by the conversion of other nutrients into carbohydrates. During periods of exertion, if the carbohydrate supply is insufficient to satisfy the fuel requirements of the tissues an increased breakdown in protein and body fat occur, and the body functions less efficiently. Therefore, adequate levels of carbohydrate function to spare protein and fat.

Cereals, which are composed predominantly of carbohydrate, are a concentrated and inexpensive source of food energy or calories. Starch makes up 90 per cent or more of the carbohydrate or nitrogen-free extract of cereals. Sugars are found mainly in the germ, while cellulose and its related materials are generally found in the bran portion. The ability of cereals and cereal products to supply high levels of calories at a low cost is an important function which should not be overlooked. However, cereals on a dry weight basis supply less calories than foods such as meat, eggs, cheese and milk. These latter foods are usually considered as high-protein foods, but they also contain high levels of fat. Since on a weight basis fat contributes twice as many calories as carbohydrate, cereal foods which are high in carbohydrates are lower in calories (Table 129).

Although dietary carbohydrate serves primarily as a source of fuel or calories there is some evidence which indicates that certain carbohydrates may be of considerable nutritional importance in addition to their primary function as food energy suppliers. Fed a low protein diet, rats grew at a better rate when cornstarch was substituted for sucrose as the source of dietary carbohydrate (Hall and Sydenstricker 1946). In these experiments the rats on the sucrose diet required additional vitamins and amino

TABLE 129[1]

CALORIC CONTENT OF CERTAIN FOODS

Food	Calories Per 100 Grams Dry Weight
Bread, white, 4 per cent non-fat milk solids	420
Bread, whole wheat	379
Corn flakes	400
Farina	413
Macaroni	410
Oatmeal	425
Rice, white	410
Cream cheese	757
Swiss cheese	607
Eggs, whole	622
Milk, whole	523
Ham	732
Beef, medium fat	640
Beef, lean	590

[1] Adapted from Anon. (1950).

acids to improve their growth. In another study rats maintained on low-protein diets, which used sucrose as the carbohydrate source, required 2 to 3 per cent more protein than rats fed a similar diet in which cornstarch replaced sucrose (Harper and Katayama 1953).

It has also been shown that the requirement of rats for niacin was greater when the source of dietary carbohydrate was fructose or sucrose than when it was glucose or cornstarch (Hundley 1949). It appears that the requirements for many members of the vitamin-B complex may be reduced when less soluble carbohydrates such as dextrin or starch are included in the diet (Harper and Elvehjem 1957).

Cereal foods contain a high percentage of starch, which may be effective in improving food utilization and in lowering requirements in certain diets for nutrients such as the B-vitamins and amino acids.

FAT

Fat and its liquid counterpart, oil, provides the body with its most concentrated source of food energy or calories in comparison to other nutrients. Fat aids in the body's utilization of other nutrients and provides essential unsaturated fatty acids which are building blocks for structural components in the cells of all tissues and essential parts of vital organs. These compounds are carriers for the fat-soluble vitamins. If fat is present in the diet in excess of bodily fuel requirements it is, unlike carbohydrate, stored in the body tissues to be drawn on to satisfy future energy requirements.

Since cereal foods are generally low in fat content (Table 127), the discussion of this nutrient will be limited.

Cereal products as consumed are low in fat content. This fact has currently become of great importance in planning diets. One reason for this is the possible relation of certain dietary fats to atherosclerosis and coronary heart disease. Another is the trend toward avoiding obesity by lowering the level of fat in the diet.

There are two factors to consider in regard to fat—the total quantity and the type in the diet. In populations subsisting on an intake of high quantities of saturated fats, the incidence of coronary artery disease is high. Examples of these saturated fats are those found in hydrogenated shortening, butter, whole milk and meat fats. A high intake of fats, especially saturated fats, has been shown in experimental studies to cause an increase in the level of cholesterol and lipids in the blood.

This accumulation of cholesterol and lipids in the blood may accelerate the development of atherosclerosis (Stare 1957). Lowering the fat content of the diet or replacing a large part of the saturated fat with fats containing high levels of unsaturated fatty acids has been shown to lower serum cholesterol concentration in adult men (Anderson *et al.* 1957). However, these are at best only preliminary findings and there is a need for more research to solve the enigma of the relationship between type and quantity of fat and atherosclerosis.

On the other hand in order to avoid obesity, the total caloric intake should be decreased. A simple means to achieve this is by lowering the intake of fat, which is a concentrated form of food energy. The removal of a portion of the fat from our diet will allow a larger intake of cereals and other low-calorie, low-fat foods. It should be emphasized that fats are necessary in reasonable quantities in the diet for satiety, improved utilization of the fat-soluble vitamins and other essential functions.

VITAMINS

General Considerations

Vitamins are defined as organic compounds which are required for normal growth and maintenance of life in animals, including man, who often are unable to synthesize these substances within their bodies. They are effective in minute amounts, do not supply energy, and are not employed in the structural building units of the body. Vitamins are essential for the transformation of energy and the regulation of metabolism of physiological processes.

Until the close of the past century the general concept of nutrition was chiefly concerned with the constituents of food then known, namely: carbohydrates, fats, proteins and water. It was believed that these substances, when present in proper proportion, supplied all the needs of the

body. Except for a few isolated reports, the curative effect of certain foods in special diseases remained for the most part unrecognized. In the early years of the twentieth century, however, this simple concept of nutrition became untenable when it was demonstrated by a number of investigators that life could not be supported entirely with these four factors alone, and that natural, unrefined foods contained small amounts of substances, heretofore unrecognized, which were essential for life. These essential substances were called "vitamins," and it was demonstrated that the absence of these factors in the diet produced specific deficiency diseases such as beriberi, scurvy, pellagra, rickets and others.

The discovery of the role of vitamins resulted in a great change, not only in the science of nutrition, but also in the treatment of certain pathological conditions which are now known to be symptoms of nutritional deficiencies. For the first time, it was clearly demonstrated that some human diseases were caused, not by toxins or by micro-organisms, but simply by the insufficiency of one or more vital nutrients in the diet.

Severe conditions of vitamin deficiency have been all but eradicated in this country by our newer knowledge of nutrition and by the prophylactic and therapeutic use of the pure vitamins. Subclinical vitamin deficiencies, resulting from inadequate diets or modern dietary habits are, however, widespread. Processed and ready-prepared foods are generally lower in vitamin content than fresh natural products and total subsistence on the former may lead to vitamin deficiencies. When a large portion of the caloric intake consists of refined sugar, as is the case in the modern dietary regimen, deficiencies of certain vitamins often result.

Certain conditions may also intensify vitamin insufficiency, in spite of the ingestion of an otherwise normally adequate diet. Increased requirements for vitamins are seen during periods of rapid growth, pregnancy, infection and fever, and gastrointestinal disturbances and other conditions which alter normal vitamin assimilation. The most important cause of vitamin deficiency, however, is the lack of an adequate diet, because of economic status and the preferences for refined, nutritionally inferior foods.

Vitamins are classified into two groups—fat-soluble and water-soluble. Vitamins A, D, E and K are fat-soluble vitamins; the B-complex vitamins and vitamin C are water soluble. Cereal products are important sources of the water-soluble vitamins. With few exceptions the fat-soluble vitamins are not found in significant amounts in cereals (Table 127).

Water-Soluble Vitamins

Thiamin—Vitamin B_1.—Thiamin was the first member of the vitamin-B complex to be recognized and isolated in the crystalline form. It is the

antineuritic vitamin and the specific dietary essential which prevents beriberi and polyneuritis. Although it was known that this specific dietary factor, a deficiency of which caused beriberi, was present in rice polishings, it was not until 1926 that it was obtained in pure crystalline form from this source by Jansen and Donath (1926). By 1931, Windaus and coworkers had isolated thiamin from yeast and established its empirical formula (Windaus *et al.* 1931). In 1936, Williams and Cline (1936) elucidated its chemical structure and several methods of synthesis were devised the same year (Greive 1936, Andersag and Westphal 1937; Todd and Bergel 1937). It is now marketed commercially as the hydrochloride or mononitrate since the free thiamin base is somewhat unstable.

Thiamin is widely distributed in the plant world and is found most prevalently in the outside bran coats of grains, especially rice (Table 127), and in yeast. Most vegetables, fruits and nuts contain small amounts, although leguminous vegetables are considered as rich sources. Since it is not stored in the human body a daily external source of this factor is required.

Thiamin is involved in proper metabolism of carbohydrates, and specifically it is concerned with the utilization of one of the intermediate breakdown products of carbohydrates, namely, pyruvic acid. It has been definitely identified as an essential part of the coenzymes associated with oxidation and reduction in living organisms.

Numerous nutritional studies have shown subclinical deficiencies of thiamin in the diets of many persons. In recent years, great advances have been made in eliminating this deficiency by the restoration of thiamin in the products that have been deprived of their natural vitamin content by processing. It is added to enrich flour, bread, rice and corn products, and other food products.

The early symptoms of thiamin deficiency are anorexia, lassitude, fatigue, emotional instability, changes in mental behavior and a lack of endurance. Advanced states of thiamin deficiency, resulting in beriberi or polyneuritis, are characterized by degenerative nerve tissue damage and by such symptons as lameness, motor and sensory nerve impairment, circulatory upset, and finally death from heart failure.

The United States Food and Drug Administration's Minimum Daily Requirements for thiamin and other vitamins and the National Research Council's Recommended Daily Dietary Allowances are tabulated in Tables 130 and 131.

In its dry form, thiamin is stable to heat. Acid solutions are stable but in alkaline or neutral solutions thiamin is destroyed by being hydrolyzed into its pyrimidine and thiazole rings. It is not subject to destruction by atmospheric oxidation, although chemical oxidation yields thiochrome.

TABLE 130

MINIMUM DAILY REQUIREMENTS OF SPECIFIC NUTRIENTS[1]

	Infants	Children (1–5 yrs. inclusive)	Children (6–11 yrs. inclusive)	Children (12 yrs. and over)	Adults	Pregnancy or Lactation
Vitamin A, U.S.P. units	1,500	3,000	3,000	4,000	4,000	..
Vitamin B_1, mg.	0.25	0.50	0.75	1.00	1.00	..
Vitamin B_2, mg.	0.6	0.9	0.9	1.2	1.2	..
Niacin, mg.	...	5.0	7.5	10.0	10.0	..
Vitamin C, mg.	10	20	20	30	30	..
Vitamin D, U.S.P. units[2]	400	400	400	400	400	..
Calcium, gm.	...	0.75	0.75	0.75	0.75	1.50
Phosphorus, gm.	...	0.75	0.75	0.75	0.75	1.50
Iron, mg.	...	7.5	10.0	10.0	10.0	15.0
Iodine, mg.	...	0.1	0.1	0.1	0.1	..

[1] Adapted from Anon. (1957).
[2] Cow's milk containing 135 units of vitamin D per quart, and evaporated milk containing 7.5 U.S.P. unit per avoirdupois ounce, usually will prevent clinical rickets when fed to normal infants in customary quantities.

a fluorescent compound which forms the basis for its analysis. In dry products, particularly in the presence of moisture, the mononitrate form is generally more stable, while in aqueous solutions the hydrochloride form is usually more stable. For instance, in enriched flour the increased stability of the mononitrate is attributed to its low relative hygroscopicity as compared to the hydrochloride.

Riboflavin—Vitamin B_2.—Riboflavin, also known as vitamin B_2, is one of the more important essential nutritional factors of the vitamin-B complex. The chemical nature of the yellow, water-soluble, green-fluorescing pigment of whey, now designated as riboflavin, was investigated as far back as 1879, but it was not until 1932 that its unique significance as a nutritional essential was demonstrated. Riboflavin was obtained from a number of natural sources during this period and its chemical properties studied. In 1935, several methods of synthesis were devised and the vitamin was shortly thereafter prepared commercially. In recent years, riboflavin has also been prepared commercially by fermentation methods.

Riboflavin is very widely distributed over the entire plant and animal kingdoms. Apparently, each plant and animal cell contains small amounts. Riboflavin is most abundant in milk, eggs, liver and leafy green vegetables. It is used extensively as an additive to foods to restore or increase their nutritional value, and is an ingredient in enriched flour, bread, corn products and other foods (Table 127). Riboflavin may occur in the free state or as a phosphate ester, both forms of which may be combined with protein material.

Riboflavin has been shown to be an essential part of an enzyme system

which, operating in conjunction with thiamin and niacin, carries out the oxidation of carbohydrates. In the form of the phosphate ester, riboflavin acts as a coenzyme in this system. The ester when attached to a specific protein, forms the yellow oxidation enzyme and appears to be present in varying amounts in practically all living cells and tissues, and is significant in all cell combustion processes resulting in the oxidation of sugars. It also appears to complement the iron-containing respiration enzyme in the red blood cells. It plays an important role in the visual mechanism of the retina. Since riboflavin is not synthesized by the cells, it must be supplied by the diet in order to obtain normal growth and development. Although the system does not contain any special organs for the storage of riboflavin, a certain level is maintained in the body. Amounts ingested above this level are rapidly excreted.

The clinical manifestations of riboflavin deficiency have been subject to considerable controversy due to the inability to determine whether the observed conditions result directly from a deficiency of riboflavin or from indirect functional effects on several other factors of the B-complex group. In general, the clinical manifestations of ariboflavinosis are photophobia, lacrimation, sore tongue and mouth, cheilosis and a keratitic opaque formation of the cornea of the eye. These conditions may often be associated with other symptoms which arise from a coexisting deficiency of some other factors of the vitamin-B complex group. While frank ariboflavinosis is rather uncommon, it is possible that a portion of our population is affected with a subclinical deficiency of this essential nutrient. This arises from a lack of this essential nutrient in the diet and, to some extent, by deficiencies or other factors which may affect the utilization of the riboflavin in the diet.

The United States Food and Drug Administration's Minimum Daily Requirements for riboflavin and the National Research Council's Recommended Daily Dietary Allowances are listed in Tables 130 and 131.

In neutral or strongly acid solutions, riboflavin is very stable toward heat but destruction is rapid in the alkaline pH range. Aqueous solutions are also very sensitive to natural and ultraviolet light, but destruction is much more rapid in alkaline solution than under acidic conditions. Riboflavin imparts a yellow color to aqueous solutions and exhibits a distinct yellowish-green fluorescence in natural light. The fluorescence, which is greatly intensified in ultra-violet light, is at a maximum at pH about 5.0 but it disappears upon the addition of acid or alkali.

Niacin.—Niacin and niacinamide are members of the vitamin-B complex. Both niacin and its amide can be used by the body and both serve the same purpose. They are specific dietary factors, a deficiency of which results in a condition known as pellagra. Nicotinic acid was first prepared

TABLE 131

FOOD AND NUTRITION BOARD, NATIONAL RESEARCH COUNCIL RECOMMENDED DAILY DIETARY ALLOWANCES, REVISED 1958[1]

Age and Sex	Weight Kg. (Lb.)	Height Cm. (In.)	Calories	Protein Gm.	Calcium Gm.	Iron Mg.	Vitamin A I.U.	Thiamin Mg.	Riboflavin Mg.	Niacin Mg.	Ascorbic Acid Mg.	Vitamin D I.U.
				Adults								
Men												
25 years	70(154)	175(69)	3,200	70	0.8	10	5,000	1.6	1.8	21	75	..
45 years	70(154)	175(69)	3,000	70	0.8	10	5,000	1.5	1.8	20	75	..
65 years	70(154)	175(69)	2,550	70	0.8	10	5,000	1.3	1.8	18	75	..
Women												
25 years	58(128)	163(64)	2,300	58	0.8	12	5,000	1.2	1.5	17	70	..
45 years	58(128)	163(64)	2,200	58	0.8	12	5,000	1.1	1.5	17	70	..
65 years	58(128)	163(64)	1,800	58	0.8	12	5,000	1.0	1.5	17	70	..
Pregnant (second half)			+ 300	+ 20	1.5	15	6,000	1.3	2.0	+ 3	100	400
Lactating (850 ml. daily)			+ 1,000	+ 40	2.0	15	8,000	1.7	2.5	+ 2	150	400
				Children Up to 10 Years								
Infants[2]												
2 to 6 months	6(13)	60(24)	kg. × 120		0.6	5	1,500	0.4	0.5	6	30	400
7 months to 1 year	9(20)	70(28)	kg. × 100		0.8	7	1,500	0.5	0.8	7	30	400
1 to 3 years	12(27)	87(34)	1,300	40	1.0	7	2,000	0.7	1.0	8	35	400
4 to 6 years	18(40)	109(43)	1,700	50	1.0	8	2,500	0.9	1.3	11	50	400
7 to 9 years	27(60)	129(51)	2,100	60	1.0	10	3,500	1.1	1.5	14	60	400
10 to 12 years	36(79)	144(57)	2,500	70	1.2	12	4,500	1.3	1.8	17	75	400
				Children Over 10 Years								
Boys												
13 to 15 years	49(108)	163(64)	3,100	85	1.4	15	5,000	1.6	2.1	21	90	400
16 to 19 years	63(139)	175(69)	3,600	100	1.4	15	5,000	1.8	2.5	25	100	400
Girls												
13 to 15 years	49(108)	160(63)	2,600	80	1.3	15	5,000	1.3	2.0	17	80	400
16 to 19 years	54(120)	162(64)	2,400	75	1.3	15	5,000	1.2	1.9	16	80	400

[1] Adapted from Anon. (1958B).
[2] No allowances are stated for the first month of life; allowances are not given for protein during infancy.

in 1867 by the oxidation of nicotine, from which it derived its name. However, its physiological role and nutritional essentiality were not elucidated until after 1930, when the occurrence of niacinamide in a number of vital enzyme systems was discovered and its specificity for the treatment of pellagra and its counterpart in dogs, black tongue, was demonstrated. In the enrichment of foods, niacin is the form usually employed.

Meat and poultry are the main sources of niacin for humans, although yeast and peanuts are also rich in niacin. Cereals furnish an appreciable quantity (Table 127), while vegetables and fruit are poor sources. Niacin is added to flour and bread as an enrichment ingredient, and has also been made a necessary factor in the enrichment of corn meal and grits.

Niacinamide plays an important role in several enzyme systems of the body. It is present in the diphosphopyridine nucleotide known as coenzyme I or cozymase, and in the triphosphopyridine nucleotide known as coenzyme II. Both of these coenzymes are essential in biological oxidations, particularly in the oxidation of carbohydrates.

Pellagra has been mentioned in the medical literature as far back as 1735 and is a common condition among the poor of subtropical countries, who subsist in a limited and unvaried diet. It has long been associated with a dietary deficiency of some factor which was first elucidated by Goldberger in the early twenties and shown to be niacinamide by Elvehjem in 1937. Although niacinamide is considered as specific for pellagra prevention, certain conditions observed in combination with pellagra are not benefited by the administration of niacinamide. These conditions, such as polyneuritis and ariboflavinosis, are now known to be due to deficiencies of other members of the vitamin-B complex; namely thiamin and riboflavin. Thus, a deficiency of one factor of the vitamin-B complex seldom occurs in fact and is usually accompanied by deficiencies of the other members.

Pellagra still exists in this country, particularly in the southern section, in individuals whose diets are principally composed of corn meal and are low in meat. The need for niacin has been shown to be related to the quantity of tryptophan in the diet, and new importance is attached to the niacin intake where corn products form a substantial portion of the diet. The pellagragenic action of corn has been attributed both to a lack of trytophan in corn protein and to the presence of a toxic material. It has been shown that the niacin needs are increased in low tryptophan diets and there is evidence that tryptophan is actually a precursor of niacin. In view of these facts, the niacin content of the diet, especially in corn consuming areas, assumes new importance.

The clinical manifestations of a deficiency of this vitamin can be summarized as dermatitis, diarrhea and dementia. A skin condition similar

to sunburn results that is dry and scaly and becomes progressively worse. Inflammation and swelling of the tongue and mouth are observed. In extreme cases, headache, vertigo, loss of memory, depression and irritability with attendant neuritis may be encountered.

The United States Food and Drug Administration's Minimum Daily Requirements for niacin and the National Research Council's Recommended Daily Dietary Allowances are tabulated in Tables 130 and 131.

Niacin is very stable in the dry form and in solution may be sterilized at 248°F. for 20 minutes without appreciable loss of potency. It is quite resistant to losses caused by normal food processing.

Pyridoxine—Vitamin B_6.—Although the compound has been known for 20 years, the need for vitamin B_6 in human nutrition has only recently been established. The first evidence of vitamin B_6 deficiency, although not recognized as such, was reported in 1926 (Goldberger and Lillie 1926). In 1934, Gyorgy and his associates demonstrated that a deficiency of vitamin B_6 produced the symptoms reported earlier (Gyorgy 1934 and 1935, Birch *et al.* 1935).

In 1938, a crystalline material isolated from rice bran was proved to have the physiological properties of vitamin B_6 and the structure of this compound was defined (Keresztesy and Stevens 1938, Stiller *et al.* 1939). In 1939, pyridoxine was synthesized (Harris and Folkers 1939).

As study continued, it was found that vitamin B_6 was made up of three separate compounds with similar structures: pyridoxine; the aminated form, pyridoxamine; and the formyl derivative, pyridoxal. The three forms are usually equal in activity for animals. In natural animal products, pyridoxamine and pyridoxal are in excess of pyridoxine. In cereal products, pyridoxine is the predominant form. Pyridoxine hydrochloride is the commercially available compound.

Vitamin B_6 is widely distributed in plant and animal tissue. Whole grains, potatoes, cabbage, bananas and uncooked meat are excellent sources of vitamin B_6. Legumes, yeast, fish, milk and sweet potatoes also are rich in vitamin B_6.

Numerous investigators have shown that the coenzyme form of vitamin B_6, pyridoxal phosphate, is concerned in amino acid metabolism and protein synthesis (Victor and Adams 1956, Schreier *et al.* 1957, Beaton *et al.* 1953, Bessey 1957). For instance, vitamin B_6 is essential for the utilization and metabolism of lysine, methionine, histidine, cystine, glycine and alanine (Wooster 1954). It is also essential for the conversion of tryptophan to niacin (Schreier *et al.* 1957, Sinclair 1953). In fact, it is so regularly involved in amino acid reactions that it has been called "the amino acid metabolism vitamin" (Bessey 1957).

Vitamin B_6 is also intimately connected with the metabolism of essen-

tial fatty acids. It has been suggested that vitamin B_6 is necessary for the conversion of linoleic acid to arachidonic acid (Rabinowitz and Snell 1948, McIntyre *et al.* 1944). Animal studies indicate that B_6 is essential to normal fat and energy metabolism. Other studies indicate that pyridoxal phosphate, the coenzyme form of vitamin B_6, is essential to proper neuronal function in the central nervous system (Coursin 1956). In studies with children, their high resistance to dental caries was attributed to the high vitamin B_6 content of the diet (Strean 1957).

Despite the extensive knowledge of the need for vitamin B_6 in human nutrition, there has, as yet, been no minimum daily requirement established for this nutrient. The daily need of the human body to insure proper nutrition has been estimated at 2 to 3 mg. (Page 1956, Vilter *et al.* 1953) and more recent evidence indicate an even higher intake may be necessary.

Pyridoxine hydrochloride is stable to heat and in acid solutions. Alkaline or neutral solutions are decomposed by ultraviolet light.

Vitamin B_{12}.—Vitamin B_{12} is a member of the vitamin-B complex. It is the most potent vitamin known, microgram quantities being required daily for the treatment of not only pernicious anemia, but also other macrocytic anemias. While the role of vitamin B_{12} in metabolism is not yet clear the compound is believed to function in enzyme systems involving the synthesis of nucleic acids and in transmethylation. It is now

TABLE 132

VITAMIN B_{12} CONTENT OF FOODS[1, 2]

	Mcg./100 Gm.
Beef liver	31–120
Beef kidney	18–55
Non-fat milk solids	2.5–4.0
Wheat flour	Negligible
Whole wheat flour	Negligible

[1] Wild *et al.* (1955).
[2] Hollenbeck *et al.* (1955).

generally accepted that vitamin B_{12} is identical with the "antipernicious anemia factor" first reported by Minot and Murphy. It is of interest nutritionally, inasmuch as it is required for the formation, maturation and regeneration of red blood cells, growth, neural function, nutritional maintenance and those fundamental processes involved in the metabolism of fats, carbohydrates and proteins Wild *et al.* (1955) have demonstrated that vitamin B_{12} stimulates the intestinal resorption and the utilization of amino acids, thus indicating a stimulation of protein synthesis.

Foods of animal origin, especially liver and kidney are rich natural sources of vitamin B_{12} while cereal products are either poor sources or completely lacking in this vitamin (Table 132).

The minimum daily requirements for vitamin B_{12} have not been definitely established, but present knowledge suggests a daily requirement of five micrograms when taken orally. Because of the low natural level of B_{12} in flour, cereals and grains, enrichment of cereal foods is very logical. In considering the addition of this vitamin to any food product, attention should be paid to those factors which affect its stability: namely, the pH, and processing temperatures, as well as the possible presence of reducing agents such as ascorbic acid and sulfites which inactivate it.

Ascorbic Acid—Vitamin C.—Although vitamin C is not found naturally to any great extent in grain products, it is being added to certain commercial cereal products and, therefore, it will be discussed here.

In 1795, the British Admiralty issued an order requiring that each seaman and marine be issued lime juice daily. As a result of this, scurvy "magically" disappeared from the Royal Navy. Today, we know that actually it was the ascorbic acid (vitamin C) in the lime juice which was the antiscorbutic factor. Currently, ascorbic acid, now well known as vitamin C, is assuming an increasingly important role in food processing and nutrition.

Vitamin C is essential to all animal life, but with the exception of man, the primates and the guinea pig, all animals so far investigated are able to synthesize their requirements. For man, a continuous external supply is necessary for existence, and a prolonged deficiency leads to scurvy and ultimately to death. Deficiencies of ascorbic acid are characterized mainly by hemorrhagic conditions, such as swollen, bleeding gums and capillary fragility, anemia, loss of weight and appetite, and fatigue. The role of ascorbic acid in the body is complex and not well understood, but it appears to have an essential part in cellular respiration and in the formation and regulation of intercellular matrices. These theories are the result of deficiency studies and observations in conjunction with its characteristic oxidation-reduction property. It is possible that ascorbic acid is involved as a structural portion of certain enzymes.

Recent literature gives indications that many diets in the United States are deficient in vitamin C, based on the Recommended Daily Dietary Allowances of the National Research Council. Nutritionists are recommending that dietary practices of many individuals must be improved to include more foods rich in ascorbic acid.

Ascorbic acid is widely distributed in the animal and plant kingdoms, citrus fruits, green vegetables and other fruits being excellent sources. Cereals do not contain significant amounts of ascorbic acid (Table 127).

The ascorbic acid content of the diet may vary widely, however, depending upon the kind of food, its storage and preparation. This is especially true since ascorbic acid is destroyed by natural enzymes in the fresh food, by heat processing and by leaching losses during cooking. Since nutritional studies have shown that our diet is deficient in ascorbic acid, the judicious restoration and addition of this essential vitamin to foodstuffs can be very beneficial.

As an added nutrient ascorbic acid has found a place in a variety of food products, such as gelatin desserts, carbonated beverages, apple juice, citrus juice blends, other fruit drinks, hard candy, breakfast cereals, soft drink tablets, beverage syrups.

The United States Food and Drug Administration's Minimum Daily Requirements for ascorbic acid and the National Research Council's Recommended Daily Dietary Allowances are given in Tables 130 and 131.

The Fat-Soluble Vitamins

Vitamin A.—Vitamin A, one of the fat-soluble vitamins, was discovered almost simultaneously in 1913 by McCollum and Davis, and by Osborne and Mendel. It is an unsaturated cyclic alcohol which is found only in the animal kingdom, occurring in the form of the free alcohol or predominantly as the ester of the higher fatty acids and related unsaturated acids. Vitamin A is synthesized from its carotenoid precursors by virtually every species of fish, bird and mammal.

Vitamin A has long been recognized as an essential nutritional factor. The biochemistry of this material is evidently contingent upon its alcohol structure which explains the ability of vitamin A to form compounds with fatty acids, proteins and bile acids. These transformations make possible the absorption of the vitamin from the intestine as the bile acid compound of the free alcohol, its transportation in the blood and lymph as fatty acid esters, and its storage in the liver in a similar form.

The growth-promoting characteristics of vitamin A are exerted indirectly through its apparent ability to maintain the normal metabolism, development and maturation of epithelial cells. Support for this contention is based on the observation that the primary effect of a deficiency of vitamin A is a keratinization of the epithelial tissue leading to a diseased condition of the cornea known as xerophthalmia.

The ability of vitamin A to form a complex which unites with protein to form rhodopsin (visual purple), a substance in the rods of the retina concerned with the accommodation of light, and to form iodopsin (visual violet), a substance in the retinal cones also concerned with vision, constitutes another well-specified function of this vitamin in the body. Night blindness has been interpreted as a manifestation of vitamin A

deficiency, which causes poor regeneration of rhodopsin. Although most diets contain an adequate amount of vitamin A, deficiencies often arise either from poor intestinal absorption, or other physiological dysfunction.

Vitamin D.—Vitamin D is the term used to denote substances which possess antirachitic properties. Vitamin D is a fat-soluble vitamin which is formed in the skin or artificially by the irradiation of specific sterols with ultraviolet light. Two active compounds of the most interest are vitamins D_2 and D_3, formed by the irradiation of ergosterol and 7-dehydrocholesterol, respectively. The function of vitamin D is not well defined, but lack of vitamin D results in loss of calcium and phosphorus and causes a deficiency condition known as rickets in infants and osteomalacia in adults. This condition is a weakening of the bone structure.

Irradiated whole milk, egg yolk and butter contain important amounts of vitamin D as do many fish oils. In addition, important amounts of vitamin D are obtained through the ultraviolet irradiation of the body.

During infancy and childhood, liberal intakes of vitamin D in conjunction with calcium are necessary to insure optimal development. The Minimum Daily Requirements for vitamin D and the Recommended Daily Dietary Allowances of the National Research Council are listed in Tables 130 and 131.

ENRICHMENT OF CEREAL PRODUCTS

In the United States modern processing techniques, which are in part a result of widespread tastes and preferences in food, severely reduce the nutritional value of many staple foods. Notable examples of this are cereal foods which are produced from highly refined grains. For example, in the manufacture of white flour, the bran and germ of the wheat kernel are removed to produce the desired white color and to improve the baking quality and stability of the flour (Williams 1948). The predominant amount of B vitamins is found in the bran and germ so removed, resulting in an inferior product in regard to these nutrients. Since these refined foods constitute a large proportion of the average American diet it is understandable that there could exist a widespread deficiency or borderline deficiency of some of the vitamins in the diet. In 1943 the National Research Council (Kruse *et al.* 1943) summed up the situation as follows:

> "All the evidence from numerous surveys over the past ten years to the present among persons of all ages in many localities is without exception in complete agreement that inadequate diets are widespread in the nation. . . . Accordingly, there is widespread prevalence of moderately deficient diets. . . . It would seem advisable to give further consideration to the program of judicious enrichment of appropriate foods since that would add much to the guarantee of successful nutrition."

Actually, these are two possible methods available to correct these deficiencies. One is to educate the public to change its dietary practices to include more of those foods which are nutritionally adequate. Secondly, foods which are staple but nutritionally inadequate may be artificially enriched or fortified. This latter approach is more rapid and feasible since food habits are rigid and not easily subject to change even after extensive educational programs.

Wheat Products

During the milling of wheat into flour, the germ and the bran are removed. Since these components of the wheat kernel contain high levels of thiamin, riboflavin and niacin, the resulting flour contains considerably less of these major nutrients.

In 1941, based on the recommendations of the Food and Nutrition Board of the National Research Council some millers and bakers began the enrichment of white flour and bread (Wilder and Williams 1944). Later in the same year a Definition and Standards of Identity (Table 133)

TABLE 133

FEDERAL STANDARDS FOR FLOUR[1] AND BREAD[2] ENRICHMENT

	Flour		Bread	
	Minimum Mg./Lb.	Maximum Mg./Lb.	Minimum Mg./Lb.	Maximum Mg./Lb.
Thiamin	2.0	2.5	1.7	1.8
Riboflavin	1.2	1.5	0.7	1.6
Niacin	16.0	20.0	10.0	15.0
Iron	13.0	16.5	8.0	12.5
Calcium[3]	500	625	300	800
Vitamin D[3] (U.S.P. units)	250	1,000	150	750

[1] Anon. (1941).
[2] Anon. (1952).
[3] Optional ingredients.

were established for any flour to be marketed as "enriched" with thiamin, riboflavin, niacin and iron with calcium and vitamin D as optional ingredients (Anon. 1941). At the same time, the War Food Administration ordered that all bakers' white bread be enriched to specified levels for the duration of the war. Later rolls were included in this order (Wilder and Williams 1944). In 1946 the Federal requirement for bread enrichment was no longer in effect. In 1952 Definitions and Standards of Identity for enriched bread, rolls and buns (Table 133) were issued under the provisions of the Food, Drug and Cosmetic Act (Anon. 1952). Federal Standards are applicable to products entering into interstate commerce. In order to have similar Standards for enriched flour and bread sold only in intrastate commerce, twenty-seven states and

Hawaii and Puerto Rico have passed statutes requiring the enrichment of all bread and flour sold within their borders.

The enrichment Standards for bread, rolls and buns are based on the flour Standards previously established, with the result that bread made from enriched flour will meet the limits set under the enriched bread Standards.

In addition to requirements for minimum and maximum levels of thiamin, riboflavin and niacin, the Standards require the addition of iron to those products labelled as enriched. Calcium and vitamin D were listed as optional enrichment ingredients and they may be added at the discretion of the manufacturer.

Alimentary Pastes.—Definitions and Standards of Identity have also been set for enriched alimentary paste products including enriched macaroni, spaghetti, noodles and vermicelli (Table 134).

TABLE 134

FEDERAL STANDARDS[1] FOR ALIMENTARY PASTE PRODUCTS ENRICHMENT

	Minimum Mg./Lb.	Maximum Mg./Lb.
Thiamin	1.7	2.2
Riboflavin	4	5
Niacin	27	34
Iron	13	16.5
Calcium[2]	500	750
Vitamin D[2] (U.S.P. units)	250	1,000

[1] Anon. (1946).
[2] Optional ingredients.

TABLE 135

VITAMIN LOSS IN COOKING OF ENRICHED MACARONI[1]

	Vitamin Content (Dry Basis)		
	Thiamin Mg./Lb.	Riboflavin Mg./Lb.	Niacin Mg./Lb.
Enriched macaroni, raw	0.96	0.40	6.6
Enriched macaroni, cooked	0.43	0.25	3.6

[1] Adapted from Anon. (1950).

Alimentary pastes are enriched at a higher level with respect to vitamins since in cooking and rinsing these products there is a significant loss of these additives (Table 135).

Farina.—Farina, which consists of coarsely ground uniform size particles of the endosperm of wheat, is used mainly as a breakfast cereal. The Standards for enriched farina are listed in Table 136.

Table 136

FEDERAL STANDARDS[1] FOR ENRICHED FARINA

	Minimum Mg./Lb.	Maximum Mg./Lb.
Thiamin	2.0	2.5
Riboflavin	1.2	1.5
Niacin	16.0	20.0
Iron	13.0	...
Calcium[2]	500	...
Vitamin D[2] (U.S.P. units)	250	..

[1] Anon. (1955A).
[2] Optional ingredients.

Methods of Enrichment.—Wheat flour may be enriched at the mill by the addition of enrichment concentrates which contain high levels of thiamin, riboflavin, niacin and iron. Vitamin D and calcium may be added to these concentrates, when desired, as optional ingredients. The enrichment concentrate is fed into the flour stream by means of various types of automatic enrichment feeders. Bread, rolls and buns may be prepared from enriched flour, in which case they meet the limits set under the enriched bread Standards. Bread, rolls and buns may also be enriched in the bakery by the addition of enrichment wafers or tablets to the yeast pot or directly into the mixer. The usual use level is one wafer or tablet per hundredweight of flour in the particular formula used. For odd weights of flour the wafers or tablets, which are scored, may be broken into fractions for correct addition level. Recently, a product has been introduced which contains an enrichment concentrate in a water-soluble envelope. The enrichment concentrate can be tailored so that one bag enriches a batch to the nearest 25-lb. increment of flour used. This water-soluble envelope may be added either to the yeast pot or to the sponge during makeup. The enrichment concentrate is completely dispersed in the dough, whether added as the wafer, tablet or envelope after two or three minutes of mixing time.

Rice Products

Rice, which is the chief cereal food of the world's population, is usually eaten as white or milled rice. This white, highly refined form of rice results when the outer layers of the rice grain are removed in milling. Rice naturally contains a high level of niacin, an ample level of thiamin and a low level of riboflavin. However, the greater amounts of these vitamins are present in the hull and are, therefore, lost during the production of polished white rice. With white rice, as with refined wheat products, the simplest method to ensure that persons eating white rice obtain the vitamins and minerals lost during the processing is by enriching

the milled grain. Federal Standards for enriched rice have recently been promulgated in the United States under the Food, Drug and Cosmetic Act (see Federal Register, Anon. 1957A and 1958A). Enriched rice is a form of milled rice (except rice coated with talc and glucose and known as coated rice) to which thiamin, riboflavin, niacin or niacinamide and iron have been added. Vitamin D and calcium are listed as optional ingredients and may be added within minimum and maximum limits. The limits of enrichment ingredients per pound are listed in Table 137. The riboflavin requirement has been held in abeyance pending a public hearing to determine if this constituent will be included in the final Standard. Nutritionally, the inclusion of riboflavin in the Standard is necessary. From the practical point of view, in certain enriching procedures the inclusion of riboflavin during the preparation of the premix imparts an objectionable yellow color to the rice kernels. This objection may be overcome by educating the consumer to accept the yellow color or by using an enriching procedure which does not impart the yellow color to the kernel.

TABLE 137

FEDERAL STANDARDS[1] FOR RICE ENRICHMENT

	Minimum Mg./Lb.	Maximum Mg./Lb.
Thiamin	2.0	4.0
Riboflavin[2]	1.2	2.4
Niacin	16	32
Iron	13	26
Calcium[3]	500	1,000
Vitamin D[3]	250	1,000

[1] Anon. (1957A, 1958A).
[2] Held in abeyance.
[3] Optional ingredients.

Unless the label bears statements in the prescribed manner to avoid washing away or draining off the enriching ingredients, these ingredients must be added in a quantity and form so that the rice contains not less than 85 per cent of the minimum quantities of these substances when washed by the method described on the label.

Methods of Enrichment.—There are a number of methods presently used to enrich rice. In one, the enrichment powder or concentrate is added to a batch of rice in a trumble or some other type of rotating drum apparatus and allowed to mix for at least 15 minutes. The enrichment powder is, to an extent, ground into the individual rice kernels by the abrasive action of the kernels rubbing against each other. Sufficient abrasive action is produced only in a drum type apparatus. Once the rice is adequately coated, more-than-normal agitation will not cause the

enrichment to flake off. Using this method of addition riboflavin, which is a bright orange-yellow color, is not readily observed on the coated rice. On cooking, it imparts a light cream-colored cast to the rice, but the color is not objectionable because it is evenly distributed.

In another method a premix is prepared by applying the vitamins in a dilute sulfuric acid solution to the rice in a rotating trumble. The rice is dusted with an iron-talc mixture and then coated with edible film, consisting of fat, abietic acid, zein and isopropyl alcohol, which is insoluble in cold water. One part of this enriched premix is mixed with 199 parts of unenriched rice to yield an enriched rice which contains the required levels of nutrients. In this method, if riboflavin is added, the rice kernels in the premix are yellow in color since they contain 200 times as much riboflavin as the unenriched kernels to which they are added.

TABLE 138

FEDERAL STANDARDS[1] FOR CORN MEAL AND CORN GRITS ENRICHMENT

	Minimum Mg./Lb.	Maximum Mg./Lb.
Thiamin	2.0	3.0
Riboflavin	1.2	1.8
Niacin	16	24
Iron	13	26
Calcium[2]	500	750
Vitamin D[2] (U.S.P. units)	250	1,000

[1] Anon. (1947).
[2] Optional ingredients.

Corn Products

Whole corn is naturally deficient in niacin and the essential amino acid, tryptophan, and low in thiamin and riboflavin. Corn is often milled, bolted and degermed to remove the major portion of the bran, germ and oil, processes which further reduce the levels of these vitamins in the finished product.

In the Southern United States where corn and its refined products such as corn meal make up a significant portion of the diet, the deficiency disease pellagra was widespread before the beginning of the enrichment program in 1947. As discussed previously, niacin is one of the most important substances for the prevention of this disease.

The Federal Government as well as certain Southern States have established Standards for various enriched corn meals and grits. The Federal Standards of Identity for enriched corn meal and enriched corn grits are listed in Table 138.

Methods of Enrichment.—Corn meal may be enriched using a method similar to that used for flour enrichment. An enrichment concentrate

is fed into the millstream or may be mixed in batches. Various types of enrichment concentrates are available which are tailored for the different types of corn meal depending upon the degree of milling the product undergoes. For instance, bolted corn meal enrichment concentrates contain lower levels of the enrichment ingredients than do degermed corn meal enrichment concentrates, because bolted corn meal is less refined than degermed corn meal.

Corn grits are sometimes washed prior to use and are, therefore, enriched by the use of a premix similar to the rice premix. The premix of corn grits is sprayed with a concentrated vitamin-mineral mixture and then coated with a film which is insoluble in cold water but which dissolves when the product is boiled. This insoluble film, which consists of a solution of zein and palmitic acid in isopropyl alcohol, protects the vitamins and minerals from being removed when the grits are washed. This enriched premix is blended with the unenriched corn grits at a level of one part premix to 799 parts of unenriched product.

Breakfast Cereals

Although there are as yet no Standards of Identity for enriched breakfast cereals (other than farina), the Food and Nutrition Board of the National Research Council in 1942 (Wilder and Williams 1944) suggested that this type of cereal product should contain the levels of thiamin, niacin and iron listed in Table 139. These levels are computed to raise the content of these nutrients in the processed cereal to at least the levels in whole grain. These cereals were referred to as restored cereals rather than as enriched. No suggestion for a level of riboflavin addition was made at that time.

Table 139

SUGGESTED AMOUNTS OF NUTRIENTS FOR CEREALS RESTORED IN THIAMIN, NIACIN AND IRON[1]

Cereal	Thiamin Mg./Lb.	Niacin Mg./Lb.	Iron Mg./Lb.
Wheat	2.0–3.0	24–36	16–24
Oats	3.0–4.0	4– 8	12–24
Rice	1.5–2.5	20–30	10–20
Corn	1.7–2.6	8–12	6–15

[1] Adapted from Wilder and Williams (1944).

VITAMIN FORTIFICATION OF CEREAL PRODUCTS

While the enrichment program has resulted in improving the levels of certain B vitamins and minerals in cereals, these food products are lacking or deficient in certain other vitamins such as vitamins A, D, C, B_6 and B_{12}. Also, many cereal products which are not included in the

Standards of Identity for enrichment are deficient in thiamin, riboflavin and niacin.

Although vitamins A, D, C and B_{12} are not found in cereals in their natural form there is no reason why they, or any other nutrient not found naturally, should not be added. In populations where there is a decided deficiency or marginal intake of a specific nutrient it is essential that these nutrients be supplied in the diet in foods which are either inexpensive or universally eaten. Cereal foods satisfy these requirements. Certain breakfast foods at present on the market are supplemented with some of these vitamins. For instance, one ready-to-eat breakfast cereal contains the following vitamins per ounce of cereal: vitamin D, 400 U.S.P. units; vitamin B_{12}, 2.5 mcg.; vitamin C, 10 mg.; thiamin, 0.4 mg.; riboflavin, 0.5 mg. Other manufacturers should consider the addition of vitamin A and vitamin B_{12} to their cereal products to improve the level

TABLE 140

VITAMIN B_6 CONTENT OF CERTAIN CEREAL GRAINS[1]

Cereal	Vitamin B_6 Mg./Lb.
Wheat bran	6.26–7.13
Wheat germ	3.86–7.26
Wheat meal	0.77–1.54
Whole wheat flour	1.73–2.72
Whole wheat bread	1.91
White flour	0.55–1.18
White bread	0.45
Rolled oats	0.42–0.68
Hulled oats	0.42
Ground rye seed	1.36–1.68
Finished rice	1.54

[1] Adapted from Sebrell and Harris (1954).

of these vitamins in our national dietary. The addition of vitamin B_{12} to cereal products in the presence of lysine and other amino acids has been shown to improve the utilization of lysine and other amino acids.

There is evidence which indicates that the American diet is marginal in regard to vitamin B_6 intake (Page 1956, Booher and Behan 1949). This is due in part to the fact that processing may seriously lower the B_6 content of food. These seem to be adequate reasons for food processors to fortify their products with vitamin B_6. One author has already recommended that bread be enriched with vitamin B_6 (Page 1956).

The fact that processing may affect the B_6 content of cereals is shown in Table 140. Wheat bran and wheat germ contain a higher level of B_6 per pound than does wheat meal or white flour. Other investigators assayed 55 samples of wheat by the rat-growth method and reported the

pyridoxine content of the various fractions as follows:

	Mg./Lb.
Wheat germ	4.36
Whole wheat flour	2.09
Patent flour	0.99

These results agree with the data in Table 140. In general, patent flour contains only one-half the pyridoxine content of whole wheat flour. Another investigator has found that the middlings of wheat contained about three times as much B_6 as the whole meal (Copping 1943).

Almost all white breads on the market are enriched so as to contain a minimum of 1.1 mg. and a maximum of 1.8 mg. of thiamin per lb. Since the adult minimum daily requirement for thiamin is one milligram, bread has been enriched to supply a substantial portion of the daily need of this essential nutrient. As stated previously, the intake of vitamin B_6 should be between 2 and 3 mg. daily (Page 1956, Vilter *et al.* 1953). However, a one-pound loaf of bread supplies only 0.45 mg. of this B vitamin. It, therefore, appears advisable to raise the vitamin B_6 content of bread to at least that of thiamin. It has been recommended that bread fortified with vitamin B_6 would be one excellent means of relieving the marginal intake of B_6 in the American diet. Processed cereals, such as breakfast cereals, are also poor in vitamin B_6 content. In addition to the fact that milled cereals are lower in B_6 content than the natural grain, it is likely that processing of cereals by toasting or drying into ready-to-eat products further lowers their B_6 content. In line with the general philosophy of enrichment, it would be good nutritional practice to fortify cereal products with vitamin B_6.

MINERALS

The body requires a number of inorganic mineral substances, all of which must be supplied by the diet. These mineral elements have various functions in the body which include the formation of bones and teeth, maintenance of acid-base relationships, maintenance of the physiological balance of the basic ions, proper function of soft tissues, and blood formation. Actually, these mineral substances have many interrelated functions and act together to regulate certain bodily processes.

These minerals are needed in small amounts in the body. They are widely distributed in food products and the turnover is slow. Therefore, with few exceptions they are present in adequate amounts in our diet. However, iron and calcium may be present in less than optimal amounts in many diets and, therefore, much of the discussion on minerals will be devoted to these two elements.

Iron

Iron constitutes a part of the hemoglobin molecule and, as such, is necessary for blood transport of oxygen and carbon dioxide. It is also vital as a catalyst in cellular oxidation. The level of iron in the body is regulated by absorption of iron from food.

The level of iron in the diet during certain periods of life may be low. In one study, 75 per cent of the subjects, age 2.5 to 5 years, received less than the National Research Council's Recommended Daily Dietary Allowance for iron. It was further stated that during the first year of life, there is a sharp rise in iron intake due to the high iron content of commercially prepared infant cereal foods. The iron intake decreases as these cereals are replaced by other foods in the diet. During periods of growth, pregnancy and lactation, the need for iron increases.

Good sources of iron are meat, eggs, green vegetables and various enriched cereals (Table 127). The enrichment of various cereals with iron has served to raise effectively the level of this mineral in the United States diet. The Minimum Daily Requirements and Recommended Daily Dietary Allowances for iron are listed in Tables 130 and 131.

Calcium

Calcium is necessary in the body chiefly for the proper development and growth of bones and teeth. In addition, calcium is an essential factor in proper clotting of blood, nerve conductivity, muscle contraction and maintenance of the normal rhythm of heartbeat. In the formation and maintenance of the skeletal structure, calcium is closely associated with phosphorus. Of the total calcium present in the body, only one per cent is found outside the skeletal structure.

Of all the minerals, calcium is the one most apt to be in short supply in the diet. In one survey, it was found that the calcium intake of women in the seventeen- to nineteen-year age group was markedly below their daily allowance as recommended by the National Research Council (Fisher and Dodds 1958). The need for calcium is the greatest in infants, who are born with a soft skeletal structure later hardened by the deposition of large amounts of calcium salts.

Milk contains relatively high levels of calcium and the addition of nonfat dry milk solids to bread and other processed cereals has raised the content of this mineral in the diet. Also, calcium is listed as an optional ingredient for various enriched cereals. Its addition to these and other cereal products has improved and will improve the level of this mineral in the diet. The Daily Minimum Requirements and Recommended Daily Dietary Allowances for calcium are listed in Tables 130 and 131.

Phosphorus

Phosphorus is necessary in the body for fat, carbohydrate and protein metabolism, proper muscle formation, acid-base regulation, vitamin and enzyme activity, brain and nerve metabolism and in proper blood formation. It is interrelated with calcium in the formation of skeletal structure. The normal diet will usually supply sufficient phosphorus. The Minimum Daily Requirements for phosphorus are listed in Table 130.

FOOD ENERGY

One of the important functions of food in the body is to supply fuel or energy to maintain body activity. This need for energy is mainly supplied in the human body by three major nutrients which comprise the largest percentage of the solids in food—fat, carbohydrate and protein. These nutrients contain potential energy which is released by their oxidation in the body cells to water and carbon dioxide and, in the case of protein, also nitrogenous compounds. The oxidation or combustion releases heat which can be measured in the bomb calorimeter as heat of combustion which is a measure of the gross energy value of a food or a particular nutrient. The unit of measure for the energy value of foodstuffs is the calorie or large calorie which is the amount of heat needed to raise the temperature of one kilogram of water one degree Centigrade.

The physiological fuel values of carbohydrate, fat and protein which are the calorimeter values, corrected for digestibility in the body and incomplete oxidation of protein, are 4, 9 and 4, respectively. These factors are useful in estimating the average fuel values of diets but are not satisfactory for specific foods or special diets. More precise data on the caloric value of foods are obtained by taking the coefficient of digestibility and completeness of oxidation of a specific food in the body into consideration (Anon. 1950).

The daily energy requirement of humans depends on factors such as age, weight and height and are taken into consideration in The National Research Council's Recommended Daily Dietary Allowances for calories listed in Table 131.

Cereal foods are a concentrated source of food energy due to their high content of carbohydrate. The caloric contents of certain cereal foods, based on 100 gm. of edible portion are listed in Table 127. Cereal foods, besides supplying significant amounts of various nutrients, are important in the normal diet as a source of calories.

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Supplementation of Cereal-Based Animal Feeds

The cereal grains and their by-products form by far the greater share of the concentrates which are fed to farm livestock in the United States. Even for those classes of livestock which depend for a large share of their nutritive requirements upon roughages, supplementation with cereal based concentrates is often necessary for efficient production and satisfactory economic returns. These roughage consumers are dairy and beef cattle, sheep, and horses. Calves, swine, and poultry must depend upon cereal based feeds as their chief source of nutrients. Likewise, pets, such as cats and dogs, can be successfully raised largely on cereal diets, even through they are classed as carnivores.

NUTRITIVE CHARACTERISTICS OF CEREAL BASED DIETS

All cereal whole grains are low or relatively low in crude fiber and high in starch. Because of this relationship, they are high in net energy and total digestible nutrient content when compared with forages. Generally, the less fiber in cereal whole grains and by-products, the higher the net energy content. Therefore, corn, grain sorghums, and wheat are high in net energy, while oats and related grains are lower.

Most grains are low in total protein content and their amino acid quality is generally poor since they contain only small amounts of the various essential amino acids required by monogastric animals. It is indeed fortunate that when ruminants receive adequate amounts of roughage, the inadequacies of cereal based rations are largely supplemented by the synthesis of good quality protein due to the activities of the microorganism population in the rumen. The same thing is true to a lesser extent for mature horses which possess large well developed colons.

In the feeding of swine and poultry of all ages, and young dairy calves, particular attention must be paid to supplying protein supplements which provide good quality protein which make up the deficiencies of cereal grains.

All grains are low in calcium and most of them are fairly low in phosphorus. Certain cereal by-products such as wheat bran and wheat middlings are fairly rich in phosphorus, while others, such as dried brewers' grains and corn gluten feed, are little higher than whole grains.

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None of the cereal grains supply any nutritionally significant amounts of vitamin D. Carotene is also low in cereal grains with the exception of yellow corn. All cereal grains are fairly rich in vitamin E. The cereals vary in their content of the B-complex vitamins. All are low in riboflavin and fair in thiamin. Corn, oats, and rye are low in niacin, while barley, grain sorghums, and wheat are high.

Most of the cereal grains are palatable to livestock with exception of rye and buckwheat when fed in large amounts as the chief grain. The chief grain used for livestock production in most sections of the United States is yellow corn. In the more western section of this country the chief grain used for livestock feeding is barley since corn does not grow well over much of the area except on certain irrigated lands.

Wheat is not very important as a livestock feed, although it is the second largest cereal crop grown as far as total acreage is concerned. Most wheat is used chiefly for the manufacture of flour and other human food.

GENERAL FEEDING PRACTICES

Ruminants and Horses

Although the rumen may function to some extent as early as three weeks of age, it is not generally considered to be fully functional until at least three to four months of age. The nutrition of the ruminant is essentially the same as monogastric animals until rumen function is established and therefore it is discussed under the heading on non-ruminants.

Rumen action accomplishes four very important nutritional functions:

1) Cellulose and other poorly digestible carbohydrates are broken down and changed to forms which are more easily utilized and digested later on in the digestive tract.

2) Many of the B-complex vitamins (including thiamin, riboflavin, niacin, pyridoxine, and pantothenic acid) and vitamin K are synthesized.

3) Poor quality proteins are changed to good quality proteins, complete in essential amino acids.

4) Non-protein nitrogen sources such as urea can be utilized in the synthesis of amino acids.

Because of the peculiar nature of ruminant digestion, dairy and beef cattle, and sheep should be fed rations which supply as large a share as possible of their requirements from roughages consistent with market demands and livestock farming practices. Such rations are usually cheaper in cost and fully as satisfactory in terms of results as those which contain higher amounts of cereal based grains or by-products. Also the ruminant animals are the only numerically important class of farm live-

stock which are able to utilize farm roughages to any great extent, and therefore fit well into many types of general livestock operations.

Although growing cattle and sheep can be maintained fairly well on roughage alone, better results are usually had if the diet is supplemented with small amounts of the cereal grains. Fattening cattle and sheep, pregnant and lactating females, all require higher amounts of concentrates in the ration for efficient production. The actual amounts and composition of concentrates to feed the various classes of stock can only be determined after a thorough examination of the individual basic feeding situation.

In order to compound a ration for ruminants it is essential to know the amount and chemical composition of the roughages consumed. Of great aid to individual farmers and ranchmen are average tables of composition such as those compiled by the National Research Council or as listed in standard reference works. (Morrison *et al.* 1956).

All adult dairy cattle and also, beef cattle on roughage type rations, should consume $1^1/_2$ to $2^1/_2$ lbs. or more of good quality hay per 100 lbs. of liveweight, or its equivalent in the form of other roughages. Fattening beef cattle will consume considerably less amounts of roughage than this when on full-feed.

Mixed-legume hays or pure legume hays are preferred to non-legume hay. Early-cut hays are higher in protein, more palatable, and contain more total digestible nutrients than those cut later in the season. Early harvesting is especially important when grass hays are used. It is usually better to sacrifice some yield for a more nutritious higher protein value crop.

Sheep will consume approximately 3 to 4 lbs. of hay or hay equivalent per 100 lbs. of bodyweight on wintering type rations. Pregnant and lactating ewes should have small quantities of grain added to the ration, while fattening lambs on full feed consume large quantities of grain. As grain consumption is increased, roughage consumption will decrease greatly. Horses will consume approximately 1 to 2 lbs. of hay per 100 lbs. of bodyweight depending upon the amount of grain being fed in the ration. Hay is generally fed free-choice in suitable racks in yards or pastures or else in the barn after being worked or at time of milking.

Corn and/or sorghum silages, and grass silages are commonly fed to cattle and sheep in large quantities when available. For sheep and beef cattle, 2 lbs. of silage equals 1 lb. of good quality hay in feeding value. For dairy cattle, 3 lbs. of silage equals 1 lb. of good quality hay in feeding value. Because of its bulky nature, silage is not usually fed to horses at hard work. For idle or lightly worked horses, brood mares, or colts, silage can be fed to replace $^1/_3$ to $^1/_2$ of the hay usually fed.

It is best to include some dry hay in the ration when silage is fed for top results with dairy, beef cattle, and sheep. When such animals are fed only silage and concentrates for fairly long periods of time, they have a tendency not to maintain gains or milk production as well as those receiving some dry hay. Milking cows should generally receive at least six pounds of dry hay in the daily ration, and fattening beef animals should receive approximately one-third of the roughage allowance in the form of dry hay.

Corn and sorghum silages are low in protein on a dry matter basis. On the other hand, grass silages are relatively high in protein on a dry matter basis. In balancing rations using silages as part of the roughage attention should be given to the kind of silage used. When large amounts of corn silage are used it is necessary to furnish higher levels of protein in the concentrate mixture than with grass silages.

The backbone of all successful ruminant livestock programs is the extensive use of suitable pastures during the growing season and/or range forages. This is because pasture and/or range is usually the cheapest method of furnishing total digestible nutrients to such animals. Legume pastures or mixtures of well adapted legumes and grasses are usually preferable to straight grasses or grass mixtures.

Proper pasture and range management is vital to securing satisfactory livestock yields. Accepted means of increasing pasture and range production include such practices as rotational grazing, fertilization, renovation, clipping, burning and irrigation.

When ruminants are on lush legume pastures it is wise to include access to dry hay of good quality in racks to prevent bloat. Most cattle will consume from 2 to 4 lbs. of such hay daily even when the pasture is excellent.

Soiling consists of cutting and/or chopping the green forage crop in the field and hauling it directly to feeding areas or lots to be fed to livestock. Its use is best adapted to cattle, although limited use has been made of this method in lamb feeding operations.

This method offers certain advantages over pasturing such as avoiding trampling of the plants, forcing the animals to consume more of the entire plant, and helping to prevent bloat. The adaptability and use of this method is dependent upon having sufficient sized operations to permit use of labor saving machinery and a long uniform growing season.

Limited use can be made of poor quality forages such as corn cobs, straws, corn stover, and cottonseed hulls by beef cattle and sheep. Dairy cattle are usually not fed such low energy materials because of the nutrient demands of vigorous fast growing heifers and lactating cows. Horses are also not usually fed such materials when at work, although

idle horses can utilize fair amounts of fodder and straws as part of the roughage ration.

Special concentrate mixtures patterned after the "Purdue Supplement A" formula to make up the deficiencies of poor quality roughages permit maximum use of these low grade materials and cheap grains. Purdue Supplement A has the following basic formula:

Soybean oil meal	650.5 lbs.
Molasses	140.0
Alfalfa meal	140.0
Bone meal	52.0
Salt (with 1 oz. cobalt per 100 lbs. salt)	17.0
Vitamin A and D concentrate (stabilized form 4,540,000 U.S.P. units D per lb.)	0.5
Total	1000.0 lbs.

Naturally, the use of such a ration does not permit as large daily gains as with conventional corn or grain—hay type fattening programs. The cereal grains are not used to any great extent in such feeding programs since the objective is to achieve cheapest gains with the maximum use of roughage. Addition of cereal grains to the ration usually reduces the consumption of such roughages markedly.

CONCENTRATE FEEDING

Dairy Cattle

Concentrates, chiefly based on the cereal grains or their by-products, should be fed according to the level of milk production, milk fat test, age and weight of cow, stage of gestation, quality and consumption of roughage, and individual needs of the cow.

Rules of thumb which are based on milk production alone, result in overfeeding the poor producers and underfeeding the good ones. A common failing of many farmers is to not consider roughage quality adequately. If the roughage is of poor quality, the concentrate allowance should be increased both in amount and in per cent of total protein. Some producers tend to overfeed protein in the concentrate mixture, resulting in wasteful high cost milk production.

If the roughage is entirely legume hay or pasture, a simple mixture of farm grains will usually be adequate unless roughage is very limited or unless the producing ability of the cows is extremely high. A 14 per cent total protein mixture is adequate for use with mixed legume roughages. If reliance is placed on fair to good pasture and/or corn silage, 16 per cent is advisable. Since dairy cattle should not be fed extremely poor roughages for good results, there is usually little reason for feeding con-

centrates over 16 per cent protein. However, droughts may occasionally force the use of all grass hays of poor quality, or rations based largely on corn or sorghum silages. In this event, the ration should contain approximately 20 per cent total protein.

Whenever possible in balancing the ration to supply the cow's daily nutrient requirements, grain feeding tables which are based on milk production and roughage consumption should be used. Still better, but more time consuming, is the feeding-standard, or nutrient-allowance method, in which the total nutrients received by the animal from all feed sources and the respective nutrients required for maintenance, growth, pregnancy and production and/or work are carefully calculated. The most commonly accepted feeding standards in use currently in North America are the Morrison Feeding Standards, while the nutrient allowances are those of the National Research Council. Although less commonly used, the same methods can be used in determining accurately the nutritive requirements for other classes of farm livestock such as beef cattle, sheep, and horses. This method is commonly used in calculating swine, poultry, and certain pet rations.

For cows of exceptional merit, theoretical calculations must be tempered with good common sense. A general rule is to feed no animal more than she can safely handle, usually a maximum of 24 lbs. of concentrates, although certain exceptions to this rule exist.

Cows on official test for milk production records are often fed either soaked or dry beet pulp in place of part of the silage or hay in order to stimulate maximum consumption of nutrients. If cows of high producing ability fail to consume sufficient feed during the height of lactation, it is wise to feed extra amounts during the later stages of the lactation period.

Dry periods of at least 90 days for young dairy cows, and 60 days for mature ones (over five years of age), are extremely important to properly condition the cow for the next lactation. Lactation is generally considered to be the most severe drain of nutrients on an animal's body, therefore the importance of this period. The amount of concentrate fed will depend upon the condition of the cow and her ability to handle feed. Generally, from 6 to 12 lbs. are fed largely based on common farm cereal grains.

Concentrate mixtures for cows of normal producing ability should contain at least 2.5 per cent fat, while those for cows of greater producing ability should probably contain at least four per cent fat. Complex concentrate mixtures made up of many ingredients apparently have not proven superior to simpler ones of the same total protein level containing fewer ingredients, and making maximum use of cereal grains and cereal by-products.

Growing heifers are usually fed low protein simple grain mixtures based largely on the cereal grains. The amount to be fed and the protein content are dependent upon the quality and amount of forage available. Usually, 1/4 to 1/2 lb. daily is allowed for each 100 lbs. of bodyweight of a 12 to 16 per cent total protein mixture.

Beef Cattle

Wintering and Stocker Cattle.—Concentrates which are for beef cattle being wintered or grazing aftermaths, such as corn fields, should be so formulated as to supplement the pasture, aftermaths, hay and/or silage which the cattle are receiving. The chief deficiencies of such a high roughage diet which should be made good by the concentrate portion of the ration are: sources of quick energy (furnished commonly by molasses), vitamin A and possibly vitamin D, protein and phosphorus. Such concentrate mixtures are often modeled after the "Purdue Supplement A" formula previously described.

Fattening Cattle.—There are many feeding methods employed to fatten cattle for market. All of them are essentially based on the use of moderate to high amounts of such high energy cereal grains as corn, sorghums, or good grade barley. When increasingly greater amounts of such grains to the limit of the animal's appetite are incorporated into the daily diet, faster gains are usually secured at the expense of decreased roughage consumption. Therefore, animals on a full-feed of grain rarely consume much over 3 to 6 lbs. of dry hay or its equivalent.

When the roughage consumption is quite limited the problem of supplying necessary nutrients in the ration becomes more critical, especially with respect to proper amount and quality of protein, vitamins A and D, minerals (especially calcium and phosphorus) and palatability. Supplements which are designed for the common grain-hay fattening type rations should therefore be designed with these points in mind.

In general, cattle on a true full feed will consume approximately 2 to 2 1/2 pounds of concentrates per 100 lbs. liveweight. Usually, the larger share of such concentrates are comprised of corn, sorghums or good grade barley as previously mentioned. Depending upon the quality and amount of roughage consumed and the weight and age of the animal, a small portion of the daily concentrate allowance is often comprised of a commercially manufactured "protein" supplement. The amounts fed of this supplement usually range between 1/2 to 2 lbs. or more per head per day.

When fast gains are not warranted by market demand or type of livestock operation, limited grain feeding often proves more economical for the farmer or rancher. This is especially true for those regions having an abundance of high quality roughage, such as irrigated alfalfa pasture and

hay, and corn silage, and which have limited amounts of cereal grain crops. Under such systems, the grain allowance is from $^1/_2$ to 1 lb. per 100 lbs. bodyweight, while the roughage consumption is approximately 1 to 2 lbs. per 100 lbs bodyweight on a dry hay equivalent basis.

Sheep

The feeding of sheep is similar in many respects to the feeding of beef cattle. Pregnant ewes are commonly fed only roughage free choice, until about 4 to 6 weeks before lambing, unless the roughage is extremely poor in quality. If the roughage is very poor it may be necessary to feed $^1/_4$ to $^1/_2$ lb. daily of any common palatable cereal grain or grain mixture to keep the ewes in the desired condition.

Four to six weeks before lambing, it is advisable to add one-half pound of a simple concentrate mixture based largely upon cereal grains which usually includes some wheat bran and high protein oil meal. When the ewes are nursing, the concentrate allowance is increased to 1 to $1^1/_4$ lbs. daily. The protein level of such mixtures is dependent upon the amount and quality of the forage consumed, and usually varies between 12 and 16 per cent.

Fattening lambs are fed high energy rations after carefully being brought up to "full feed." Full feeding of lambs is more hazardous and risky than full feeding of cattle. Therefore, close care and experience are necessary to prevent "off feed" conditions from developing. A typical fattening ration for a 70-lb. lamb on full feed is as follows: Legume hay, 1.4 lbs.; Corn or grain sorghum, 1.5 lbs.

The addition of 0.1 lb. high-protein supplement will increase the gains a trifle, but will usually not be profitable. Many variations are to be had from the quoted example, due to differing market conditions, crops, and livestock husbandry management methods.

Use of Urea as Protein Replacement in Ruminant Rations

Because of the peculiar nature of the ruminant digestive system, the micro-organisms in the rumen are able to utilize urea, ammoniated molasses, cyanamid and ammonium sulfate as replacements for part of the protein in the ration. This non-protein nitrogen is first changed into ammonia in the rumen, and then is quickly combined with non-nitrogenous compounds in the building of bacterial protein. Further on in the digestive tract, the bacteria are themselves digested, and thus this protein made available to the animal.

For dairy cattle, the results are usually best when not more than 1 per cent of the entire ration, or 3 per cent of the concentrate ration is made

up of urea or its equivalent. It also appears that results are best with rations low in natural protein.

For beef cattle and sheep, urea-soybean and corn based pellets and mixtures have given fair to good results with such poor quality roughages as straw, ground corn cobs, and poor hay.

Urea is ordinarily not very palatable to ruminants, and consequently should be mixed with such well-liked ingredients as molasses. Urea is utilized best when it is fed in combination with cereal grains or some other starchy concentrate. Because of the danger of urea intoxication, care should be used in formulating and manufacturing such feeds. Urea cannot be utilized and is not incorporated in non-ruminant rations.

Making Up the Deficiencies of Cereal Grains in Ruminant Rations

It is indeed fortunate that the common nutritive deficiencies of the cereal grains are largely made up by nutrients contained in the large amounts of roughage consumed in the usual ruminant rations in combination with the benefits of the microbial activity in the rumen. In the feeding of ruminant animals little attention is commonly given to such points as quality of protein, deficiencies of B-complex vitamins, deficiencies of vitamins A and D, and, usually, lack of calcium.

Unless roughage is very limited in the ration, as for example, with fattening cattle and sheep, the common considerations are only those of energy or total digestible nutrients, calcium, phosphorus, digestible protein, and carotene (or vitamin A). With fattening cattle or sheep on full feed, it is likely necessary to evaluate more critically the ration in terms of amino acid balance and protein quality, although this point is disputed by certain authorities (Albert *et al.* 1957, Dyer and Fletcher 1958).

Good well-cured hay is usually high in vitamin D and even barn-cured hay and grass silage contain small amounts which are probably sufficient for good health. Also, since farm animals usually have some direct exposure during at least part of the day to direct sunlight, vitamin D deficiency is rarely encountered. Ergosterol contained in the skin secretions in direct sunlight is converted to active vitamin D and reabsorbed by the body.

Ample use of good green-colored roughages, indicative of high carotene content, prevent a deficiency of vitamin A. Furthermore, ruminants have the ability to store vitamin A in the liver during periods of excess consumption enabling them to withstand periods of dietary insufficiency.

Legume roughages are rich in calcium and the requirement for this mineral is met if ample amounts of such hays are fed in the ruminant diet. Although there is rarely a lack of calcium if grass hays or corn

silage are extensively used, 10 to 20 lbs. of ground limestone added per ton of concentrate grain ration will amply make up any lack.

Phosphorus is important in most ruminant rations, and a common commercial practice is to include 20 lbs. per ton of concentrate mixture of some good available phosphorus source such as defluorinated rock phosphate, dicalcium phosphate or steamed bone meal. If large amounts of phosphorus rich by-products ingredients are included in the concentrate mixture such as wheat bran or the various oil meals, it is possible to reduce or eliminate the mineral phosphorus carriers in certain rations.

The importance of adequate phosphorus in the diet of fattening cattle is just now being appreciated (Burroughs 1956, Long *et al.* 1957). An excess of calcium in the diet may depress the digestibility of ruminant rations.

Many farmers and ranchers also supply mineral mixtures free-choice which are available at all times to ruminant animals. A common mineral mixture for feeding to these animals is as follows: 60 parts of steamed bone meal, 20 parts of ground limestone, and 20 parts of salt.

Consideration should be given to the protein level of the diet which the ruminant receives. This is based entirely on the amount and kind of forage being consumed. Those animals receiving large amounts of legumes do not require as high protein in the concentrate grain mixture as those receiving only grass hays or corn silage, etc.

Horses

Horses are commonly fed grass hay such as timothy, as the chief roughage, and oats, as the chief grain. Legume hays, such as alfalfa, can be used by horses successfully, if free from mold and dust, and consumption is restricted to actual body needs. In general, about 2 lbs. of total feed or a little more per 100 lbs. bodyweight are required by horses.

For horses doing no work the entire feed allowance can be made up of roughage alone. For horses doing light to average work, approximately $^1/_3$ to $^2/_5$ of the feed allowance is made up of grain, the balance being roughage. For horses at hard work, approximately $^3/_5$ is grain, and $^2/_5$ roughage.

Corn may be substituted in horse rations, but less is used because of its higher energy content. The use of small amounts of linseed oil meal or other protein supplement is recommended when feeding corn to horses, because of its lower protein content.

Non-Ruminants

Swine are the only non-ruminant large farm animals which are of importance in livestock programs.

Horses are numerically small and although non-ruminants have been discussed previously under the heading **Ruminants and Horses** because they are able to utilize large quantities of forages in their daily ration, due to the extensive development of the large colon and caecum.

Nutritionally speaking, poultry are usually classed and discussed as non-ruminant animals. They are of great economic importance to both the agriculture and feed industries. Poultry feeds of all descriptions account for the largest share of commercially mixed feed sales in the United States.

Poultry and swine rations are characterized chiefly by the following points:

1) *Relatively low in fiber and high in energy compared with most rations fed to ruminants,* except those for fattening sheep and beef cattle. Roughages are therefore utilized only to a very limited extent. Extensive use is therefore made of the cereal grains and their by-products.

2) *Protein of the proper amount and amino acid quality is necessary.* Both poultry and swine require certain "essential" amino acids to be supplied in their rations.

The essential amino acids required by both swine and poultry are: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. In addition the chick requires glycine (or serine, or a combination of serine and arginine).

In the chick and probably also swine, cystine may partially replace the requirement for methionine, and tyrosine may partially replace the requirement for phenylalanine.

3) *Additional amounts of certain of the B-complex, vitamins A, D, and possibly E, and K,* are necessary, since there is little or no synthesis of the B-complex vitamins, and the fat-soluble vitamins may be limiting in the feedstuffs used.

4) *Additional amounts of the major minerals are needed,* such as calcium, phosphorus, and sodium chloride. *Also minor amounts of trace minerals* such as copper, cobalt, iron, zinc, manganese, magnesium, and iodine are commonly added to both swine and poultry feeds. Although proven deficiencies of all of these trace minerals may not exist in some areas, most feed manufacturers usually add some or all of them to the ration as insurance against possible lacks.

5) *Sources of the "unidentified growth factors" are usually included in poultry rations, and, to some extent, in swine feeds.*

The exact nature and mode of action of certain natural feed ingredients and/or minerals which promote better growth in poultry are as yet un-

known. Most authorities consider that the following unidentified factors are usually required by the chick and poult for maximum growth:

a) *Fish factor*—supplied in largest amounts by fish solubles, fish meal, hydrolyzed feather meal, liver meal, and certain fermentation products.

b) *Distillers solubles factor*—furnished by grain or molasses distillers solubles and yeast.

c) *Alfalfa factor*—supplied best by fresh green forage, grass juices, dehydrated alfalfa meal, dehydrated legume, grass, and cereal forages, dairy by-products and brewers' dried yeast.

d) *Whey factor*—present in dairy by-products, yeast, and certain other feeds.

The usual commercial practice is to furnish at least two or more sources of unidentified growth factors in the rations of young poultry. Commonly, a level of 40 to 50 lbs. each per ton of mixed feed is used.

Recent evidence also indicates that the "unidentified growth factor" response is not only due to organic factors present in certain natural feedstuffs, but also, due to inorganic factors (Reid *et al.* 1958, Norris *et al.* 1958, Supplee 1958).

These experiments, usually conducted with purified rations, indicate that small amounts of bromine, sulfur, zinc, molybdenum, and selenium may all be required in chick and poult rations. At present, the feeling is that natural feedstuffs present in the accepted rations usually contain sufficient amounts of these trace minerals to insure adequate growth and results. It would be unwise, in many cases, to add supplementary amounts to the ration, since many of these trace minerals are toxic in excessive amounts.

Evidence from certain experiments indicates also that swine may perform somewhat better if certain sources of the unidentified growth factors are included. (Catron 1958A, Hare *et al.* 1956) A source of the alfalfa factor is commonly considered to be important in swine nutrition. The value or importance of the other sources of unidentified growth factors in swine nutrition must await the outcome of further research.

Swine Feeding. Importance of Roughages.—Although roughages do not form any large part of swine rations, their importance under certain conditions cannot be overemphasized in practical hog farming. Whenever possible, swine should be provided with good pasture during the growing season, and with well-cured legume hay or dehydrated legume forage when pasture is not available. These are especially needed by young pigs, brood sows and gilts. This fact is of extreme importance in reducing the cost of pork production and preventing nutritive deficiencies.

There are generally no vitamin deficiencies when swine are fed sufficient good quality hay or are on good pasture. Also, the protein require-

ments are reduced when swine receive good quality hay and pasture. The protein of these roughages is of such quality that it helps to correct the deficiencies of the cereal grains which make up the large share of the diet. Fair gains can be made by swine on lush legume pasture, which are fed corn or other cereal grains free-choice, supplemented with a mineral mixture containing both calcium and phosphorus. However, still better results are had if a good quality protein supplement such as tankage is also offered to the pigs.

Legume roughages are rich in calcium and also in the "alfalfa factor." Full-fed growing and fattening pigs do not consume large amounts of good roughage. Therefore, when they are liberally fed on corn or other low-protein grains, they will not eat enough of such roughage to properly balance the ration in protein. In order to secure economical and rapid gains, it is necessary to add a sufficient amount of an efficient, concentrated good quality protein supplement to furnish the required amount of protein.

Serious deficiencies occur when brood sows are raised and kept in dry lot continuously, in spite of the many recent improvements and developments which have been made in meeting the nutritional requirements of swine in dry lot. Even rations calculated to be entirely adequate in all known vitamins, minerals, amino acids, and unknown growth factors, in light of today's knowledge, are not ideal for breeding pigs in dry lot over a long period of time. It is therefore important to allow brood sows and breeding boars to have access to pasture during the growing season, supplemented with good quality hay or dehydrated forage at other times of the year.

Silage is not commonly fed to any great extent to either swine or poultry. It can be used for pregnant sows when supplemented with protein and minerals, but is too bulky in nature for use by growing and fattening swine.

Supplementation and use of cereal grains in swine rations.—Since none of the cereal grains furnish protein of good quality, it is very necessary to furnish protein supplements in the ration which make up the amino acid deficiencies present in all cereal grain diets. Skim milk, other dairy by-products, fish meal, digester tankage, meat scraps, and properly processed soybean oil meal all provide protein that corrects the protein quality deficiencies of the cereal grains. Any one of these supplements can be used alone, or in combination with the others, for swine on good pasture. If the swine are on dry lot, legume hay or dehydrated forage should be incorporated into the ration. Usually, somewhat better results are had if combinations of protein supplements are used than if only one single one is used alone. Cereal grain by-products which are fair to high

in protein are not satisfactory either singly or in combination as protein supplements for swine. Such materials are: wheat middlings, corn gluten feed, corn gluten meal, rye feed, brewers' dried grains, distillers dried grains, etc. Pigs so fed make slow and expensive gains. Feeds which incorporate modest amounts of these cereal by-product ingredients along with larger amounts of better quality protein rich ingredients furnishing good amino acid balance, are entirely acceptable to hogs and will give good economical gains.

Swine are usually fed either self-fed or hand-fed. Complete feeds, which include a mixture of ground cereal grains, a proper proportion of protein supplements of good quality, minerals, and vitamins; may be used with either method. Complete feeds may be mixed either on the farm or by commercial feed manufacturers.

The special committee of the National Research Council has recommended in its report on "Nutrient Requirements of Swine" that rations for growing and fattening pigs should have the following percentages of total protein: at a weight of 25 lbs., 18 per cent; at 50 lbs., 16 per cent; at 100 lbs., 14 per cent; at 150 lbs., 13 per cent; and at 200 lbs. or over, 12 per cent.

For pregnant females and breeding boars, 15 per cent protein is recommended for young stock and 14 per cent for adults. For lactating gilts 15 per cent is recommended, while for lactating sows 14 per cent is advised.

When swine are on good legume pasture, approximately two per cent less protein than the levels advised above will give satisfactory results. When protein supplements are unusually expensive, it may be more economical to use lower levels of protein than commonly recommended, although daily gains will be smaller.

Pigs show a remarkable ability to balance their rations in protein when they are self-fed low protein cereal grains such as corn, and also self-fed separately *certain* single protein supplements or *certain* supplemental protein mixtures. The results from this method are usually fully as satisfactory as when complete mixed feeds are used, especially for hogs weighing over 75 lbs. (Hanson 1958, Becker 1958, Wingert 1958, Catron 1958, and Cunha 1958). For hogs weighing less than 75 lbs., and particularly for weanling and nursing pigs, complete feeds are somewhat preferred.

With the exception of salt (usually supplied in mineral mixtures, and/or mixed in the feed at the rate of not over one-half pound salt per 100 lbs. feed), calcium is the mineral most apt to be deficient in swine rations. This is because the grains and their by-products and most protein supplements of plant origin are low in this mineral. Fortunately, animal pro-

tein supplements and most forages are high or relatively high in this mineral. Whether or not there will be any benefit from the addition of a calcium supplement will depend entirely on the type and nutrient composition of the ration. An excess of calcium in the ration will decrease gains and tend to cause parakeratosis (Lewis *et al.* 1957, Lewis *et al.* 1957A, Hoefer 1956).

There is generally no lack of calcium in swine rations when animal protein supplements are fed in sufficient quantities to balance the ration. However, when plant by-products such as soybean oil meal, linseed meal, or wheat middlings, etc., are used, the addition of a calcium supplement to the ration is advised. Since most commercially mixed protein supplements used for hogs today are based on a combination of both plant and animal by-products, additional calcium is incorporated into the mixture.

A deficiency of phosphorus is much less apt to occur in swine rations than calcium simply because most protein rich supplements needed to balance the ration are rich in phosphorus. Also, although, the cereal grains are not rich in phosphorus, they contain more phosphorus than calcium. Pigs apparently utilize phytin phosphorus, which forms a considerable part of the phosphorus in feedstuffs of plant origin, better than poultry. Whether or not it is advisable to add a phosphorus supplement to swine rations depends entirely upon the nutrient composition. Swine should receive rations which have the proper calcium to phosphorus ratio of 1.1 : 1 to 1.5 : 1.

In iodine-deficient areas, brood sows need iodized salt or some other iodine source to prevent hairless pigs. To avoid simple anemia of suckling pigs without access to pasture or soil, traces of iron and copper must be supplied in some manner. Usually, swabbing or spraying the udder of the nursing sow or gilt with a saturated solution of commercial grade ferrous sulfate until the piglets are 4 to 6 weeks old will prevent this condition. Other methods such as giving each baby pig oral doses of iron solution once each week, or injecting them with an iron-dextran complex solution are also used.

In areas where proven deficiencies of copper, cobalt or other trace minerals exist, it is essential that the lack be corrected in the ration. If no deficiency is apparent, there is no benefit from adding such minerals to the ration of hogs on pasture. In certain experiments with hogs in dry-lot, trace mineral additions have proven beneficial, and most commercial manufacturers add trace minerals to their feeds, especially those meant for hogs on dry-lot. The addition of small amounts of zinc to the diet has recently been proven beneficial in preventing the development of parakeratosis in swine (Hoefer 1956).

Although vitamins A and D are of great importance in swine feeding, those on good pasture have their needs for these vitamins amply taken care of. This is because good pasture is rich in carotene which is converted by the animal to vitamin A, and because the vitamin D needs are taken care of by the anti-rachitic effect of direct sunlight acting upon the ergosterol secreted onto the skin of the animal, being reabsorbed as active vitamin D. Also since high quality pastures are able to supply the B-vitamin requirements of pasture fed swine, there is little reason to include B-complex vitamins in rations meant for pasture feeding. In ordinary swine rations there are no known deficiencies of vitamin E. Vitamin C can be synthesized by the body and does not need to be included in the ration.

Legume hay of good quality will not only supply carotene or vitamin A value to the ration, but it will also furnish vitamin D, and the B-complex vitamins, except vitamin B_{12}; thus, the importance of including good quality legume hay or suitable forages in the ration of dry-lot swine. Commercially mixed feeds often include additional sources of vitamin A and D in the form of refined fish oils, or vitamin A in the synthetic form and vitamin D from irradiated yeast or irradiated ergosterol. Various methods are used to improve the stability of these products, such as wax and gelatin coatings, etc.

The various breeds of swine seem to differ markedly in their vitamin D requirements, and if they have plenty of calcium and phosphorus, white pigs do not usually exhibit any symptoms of a vitamin D deficiency when kept under the same conditions causing deficiency symptoms in black or red pigs. Unless pigs are very closely confined and have no access to direct sunlight, five per cent of good-quality field-cured legume hay in the ration will prevent any deficiency symptoms. If pigs are closely confined, or if dehydrated roughages are used, the use of a vitamin D supplement is advisable. Including 0.5 to 1.0 per cent of cod-liver oil or 0.125 to 0.25 per cent of a cod-liver-oil concentrate in the ration will furnish sufficient vitamins A and D in the ration even when no legume hay is fed in the ration.

There is only limited synthesis of the B-complex vitamins in the intestines of swine by bacterial action, thus, they are dependent chiefly upon the supply of these vitamins in the feed to meet their bodily needs, differing from ruminants.

When swine are on good pasture, they are rarely deficient in the B-complex vitamins. Also, when good quality legume hay or alfalfa meal is included in the rations of swine in dry-lot, there are normally no lacks of B-complex vitamins with the exception of vitamin B_{12}.

Any ordinary ration for swine usually furnishes an abundance of thiamin, plenty of pyridoxine, and enough choline. The B-complex vitamins which deserve attention in most swine rations are riboflavin, niacin, pantothenic acid and vitamin B_{12}.

Rations which are made up chiefly of corn, soybean oil meal, minerals, and five per cent alfalfa meal are usually somewhat low in riboflavin for young pigs in dry lot. If the alfalfa meal is increased, or part of the soybean meal is replaced by some animal by-product, or by such feeds as distillers dried solubles, and dried brewers' yeast, the lack is corrected.

The niacin content of both corn and oats is considerably less than that of barley, the grain sorghums or wheat. This is important in some instances, particularly in dry-lot rations fed to very young pigs. Occasionally, young pigs fed rations high in corn and/or oats suffer enteritis from a lack of niacin. This is due to the fact that the niacin content of certain lots of corn and/or oats is below the average figures which are quoted in tables of nutrient composition. High corn rations are also low in tryptophan. Niacin can be made from tryptophan by the animal in its body. Thus, a deficiency of tryptophan further accentuates a deficiency of niacin.

Correction of niacin deficiencies in such rations can be made by adding alfalfa meal, wheat middlings, animal by-products, dried distillers' solubles and/or dried brewers' yeast, all of which are high in niacin. Enteritis caused by a nutritional deficiency of niacin must not be confused with that caused by infection.

Although rare on pasture, a deficiency of pantothenic acid can occur in dry-lot with swine fed chiefly the cereal grains balanced with minerals and such protein supplements as meat scraps, tankage, and fish meal. This is because these animal protein supplements are low in pantothenic acid, while the cereal grains are only fair. A characteristic symptom of pantothenic acid lack in pigs is a "goose-stepping" incoordinated gait. Such ingredients as soybean oil meal, linseed meal, wheat middlings, distillers' dried solubles, peanut oil meal, dried buttermilk, dried skim milk, dried whey, dried brewers' yeast, and cane molasses are useful sources of this vitamin in formulating swine rations.

With the discovery of vitamin B_{12}, it was found that much of the benefit in dry-lot hog rations of animal by-products was due to their vitamin B_{12} content. Feeds of animal sources, such as meat scraps, tankage, fish meal, dairy by-products, condensed fish solubles, and liver meal are used by commercial manufacturers to supply vitamin B_{12} in swine rations. Although the usual methods of analysis do not reveal a very high content of vitamin B_{12} in fresh growing pasture plants, hogs on pasture show no evidence of a deficiency of the vitamin. Either sufficient is synthesized

in the intestines of pasture-fed pigs, or else, they secure the mere traces of the vitamin required from the insects and worms they consume.

A lack of vitamin B_{12} is much more apt to occur with young pigs than with older ones. Commercial feed manufacturers often include synthetic or concentrated natural sources of certain of the B-complex vitamins if the ration composition indicates a need for such supplementation, especially in those rations designed for younger pigs.

Although the studies are conflicting, swine may need sources of certain "unidentified growth factors" in some dry-lot rations. Pasture apparently supplies the unidentified factors, and no lack is found in this respect when swine are on good pasture. The unidentified factors which may be required possibly by swine under certain conditions are claimed to exist in alfalfa meal or grass juice, milk by-products, fish solubles, and certain fermentation residues. Very likely, further research will elucidate when and under what conditions additional amounts of these sources are needed. Many commercial feed manufacturers add small amounts of one or more sources of the unidentified growth factors to their swine feeds, especially those for young pigs, as a matter of insurance.

There is some variation in the feed consumption of pigs, depending upon the type of feeds, management methods, and type and class of animal. In general, full-fattening swine will consume 3 to 5 pounds of feed per 100 lbs. live weight. According to age, the younger pigs consume proportionately the larger ration. Good forage will reduce protein requirements, and usually results in production of pork for somewhat less total pounds of concentrate feed.

Pregnant sows should not be allowed to consume all they will eat, since overfatness reduces litter size. A good rule of thumb is to limit consumption of feed to 1 to $1^1/_2$ pounds per 100 lbs. bodyweight, offering plenty of pasture or legume hay free-choice. Sows can be self-fed, but when this is done it is necessary to incorporate 25 to 40 per cent or more of coarse fibrous bulky feeds such as hay, alfalfa meal, or corn cobs to prevent overconsumption. Sows nursing litters will consume 3 to 5 pounds of concentrates per 100 lbs. bodyweight daily depending upon the size of the litter and availability of pasture.

Boars not in active breeding service should receive approximately 1 lb. per 100 lbs. bodyweight of concentrates when on pasture, and slightly more when in dry-lot. Two weeks before the breeding season the boar should be fed enough to be gaining in weight when service begins. During the breeding season, he should be fed enough to prevent loss in weight. The actual condition of the boar itself is the only reliable guide as to amounts to feed.

During recent years there has been considerable interest in the wean-

ing of pigs at much earlier ages than formerly advised or thought possible. Such early weaning, commonly at 3 to 4 weeks of age, permits two or more litters per year from the sow, greatly reducing the cost of producing pork. When early weaning is practiced, it is usually necessary to use farrowing-crates, extremely good management, and careful sanitation and disease control methods.

Special pre-starter creep-feeds have been designed for use by early weaned pigs. These special feeds are not commonly mixed on the farm because of their complex formulation and the small amounts of certain micronutrients added to the feed. Such feeds are usually high in rolled oats or hulled oats, milk by-products, and sugar to increase their palatability. Critical attention is needed to secure the correct amino acid balance, mineral levels, and vitamin requirements in such feeds.

Weaning pigs younger than three weeks of age is not recommended since this is not practical under most farm conditions. Such pigs must be fed an expensive milk-replacer type of formula, and often do not respond well later on in the growing-fattening phase of the hog raising program.

It is common practice on many farms which wean pigs at the normal ages of 6 to 8 weeks, to offer the nursing piglets a pig-starter in creeps. This reduces the shock and set backs of weaning and supplies the young pigs with as great an amount of nutrients as possible during a period of very efficient growth.

Poultry Feeding.—*Supplementation and use of cereal grains in poultry rations.* Poultry are similar in their nutritional needs to swine with certain minor exceptions, in spite of the anatomical differences of their digestive tracts. Relatively more is known about the various requirements of poultry than swine because of the greater ease and cheaper cost of testing with larger groups of experimental subjects. Modern rations permit the keeping of chickens in total confinement without suffering to any great extent in production or breeding efficiency; this was not possible only a few years ago.

It is necessary to supply poultry with diets which make up the amino acid, vitamin and mineral deficiencies of the cereal grains. Most animal by-products and properly processed soybean oil meal furnish protein of such quality that the deficiencies of cereals are largely corrected. Legume hay, or preferably dehydrated forages, are included in most rations for poultry when not on poultry range, to supply protein of good quality, furnish vitamin A value, supply certain B-complex vitamins, and furnish the alfalfa factor.

Poultry, especially broilers and young turkeys, are fed complete mixed feeds manufactured by commercial companies. Broiler feeds represent

the largest single classification of feed tonnage in the United States. Farm grains are often fed along with commercially manufactured protein-mineral-vitamin supplements to such classes of poultry as growing or replacement birds, layers and breeders on a hand-fed or free-choice basis.

Today, commercial broiler raising and feed formulation has become a business largely conducted by big operators closely integrated or allied with commercial feed manufacturers, hatcherymen and breeders. The formulas are usually so designed as to be nutritionally complete at the very lowest possible cost. Modern linear programming and electronic calculating methods have been adapted to aid the nutritionists in developing such rations. Due to the variability in types of ingredients used and manufacturing and husbandry methods, only the most general discussion of basic principles of formulating such complex rations can be given.

Most commercial broiler rations use higher percentages of total protein than are commonly recommended for commercial chick starters and growers designed for replacement laying and breeding birds. A broiler starter usually will have from 23 to 25 per cent protein, while a broiler finisher will have from 20 to 23 per cent protein. Most broiler starters are fed during the first 4 to 6 weeks of life, while broiler finishers are fed from the time the birds are removed from starter until marketing (approximately $8^1/_2$ to 10 weeks of age).

Most commercial chick starters contain 20 to 23 per cent total protein while most growing rations contain 15 to 19 per cent total protein. Although recent experiments indicate that properly formulated rations as low as 12 to 13 per cent total protein may be satisfactory for layers, the usual conventional rations contain 15 to 18 per cent total protein.

Largely because they grow at a faster rate than chickens, poults require a greater percentage of protein than chicks. Also, their requirements per pound of feed are greater for calcium, phosphorus, vitamin A, vitamin D, and riboflavin.

When poultry are hand-fed or free-choice fed farm grown grains along with a commercial protein-mineral-vitamin supplement, the protein level of the supplement is so calculated that the recommended total protein content of the entire ration is achieved.

Formula feed manufacturers pay close attention to the balance between total protein, amino acids, and the calories of metabolizable energy, or productive energy, in broiler and other poultry rations.

Soaking certain types of western barley in water seems to improve the productive energy value of the grain so it approaches that of corn (Fry *et al.* 1958). Addition of enzyme cultures to western barley is also reported to have a similar effect (Fry *et al.* 1958).

Pelleting of poultry feeds increases the density of the feed allowing the birds to consume more total feed. It was recently reported that a broiler feed containing only two per cent added animal fat was as efficient and more economical than an all-mash broiler feed containing ten per cent added animal fat (Combs 1958A).

Cereal grain based rations for chicks and turkeys, especially heavy-breed broilers and turkey poults, in which reliance is placed upon soybean oil meal, peanut oil meal, and degossypolized cottonseed oil meal as the only or chief protein supplement, are often somewhat deficient in the essential amino acid methionine. Supplementation of such rations with either dl-methionine, liquid methionine hydroxy analogue, or methionine hydroxy analogue calcium have usually improved feed conversions, and occasionally liveweights. Only 0.5 to 1.0 lb. of methionine source is necessary to bring about the desired response in most cases.

The addition of stabilized animal tallows or greases and vegetable oils to commercial broiler feeds, and even to certain other poultry and swine feeds is becoming fairly standard practice. The fat addition increases the energy value of the feed and usually lowers the amount of feed eaten to produce a pound of gain or produce a dozen eggs. Although experimental diets containing 30 per cent or more fat have been fed to broilers with good results, the usual commercial practice is to add from 2 to 6 per cent of fat in most broiler rations at present.

The requirements for calcium and phosphorus by poultry are greater than those of the larger farm animals. Special consideration must be given in designing poultry rations to insure adequate intakes of these two minerals. The calcium requirement is particularly high because of the rapid growth of chicks and growing poultry, and because laying birds need large amounts to form good hard eggshells. Rations for laying hens should contain 2.25 per cent in the total ration, ones for chicks should have 1.0 per cent, and those for growing turkeys approximately 2.0 per cent. With laying hens it is a common practice to include only part of the calcium requirement in the feed, and to also provide the hens with access to oyster shell or limestone grit at all times.

Although the National Research Council recommends 0.6 per cent total phosphorus in the ration for chicks, growing birds, and hens; modern broiler rations usually have somewhat higher levels than this.

It is important in feeds for chicks and growing birds to supply a large share of the phosphorus in an inorganic form, since these classes of poultry do not utilize phytin phosphorus well. Since as much as three-fourths of the phosphorus in grains and the by-products of grains and other seeds may be in the form of phytin phosphorus, it is usually necessary to include such inorganic phosphorus supplements as defluorinated rock phos-

phate, bone meal, or dicalcium phosphate in rations for chicks and growing birds.

Salt is needed by poultry, but the requirement is relatively small. Normally, from 0.25 to 0.5 per cent in the total ration is ample with the usual ingredients used.

Particular attention must be paid to the manganese content of poultry rations to prevent the development of perosis or the slipped tendon condition, and to promote good egg production and hatchability. Deficiencies of manganese are most apt to occur when the birds are kept in strict confinement with no access to poultry range or sunlight. Deficiencies of certain B-complex vitamins such as choline, biotin, and folic acid increase the requirement for manganese in the ration. Assimilation of manganese is also impaired by rations high in calcium and phosphorus.

A deficiency of manganese is not apt to occur when the feed contains a fair amount of such ingredients as wheat bran, wheat middlings, rice bran, fish meal, soybean oil meal and alfalfa meal. Most commercial feed manufacturers add one-quarter pound of manganese sulfate per ton of complete feed to guard against any possible deficiencies of this mineral.

Although most poultry rations are probably adequate in iodine, it is common commercial practice to add iodized salt or some other source of iodine to such feeds. It has been recently demonstrated with purified diets that chickens may require certain other mineral elements such as sulfur, zinc, bromine, molybdenum, and selenium in their rations (Norris *et al.* 1958, Combs 1958, Supplee 1958). It is highly unlikely that the usual practical-type rations will be deficient in such minerals.

Grit should be supplied to laying and breeding chickens in form of an insoluble granite or quartz grit. Such grit aids the gizzard in grinding whole grains and coarse feed particles, reducing feed requirements and increasing egg production. If all-mash rations are fed, the addition of grit is desirable but it may not be absolutely necessary for satisfactory egg production or feed efficiency. Experiments vary as to the effectiveness and desirability of incorporating or furnishing grit in broiler rations, and although it is likely desirable, no firm recommendation can be made for supplying grit up to 4 to 8 weeks of age.

When poultry are not on good ranges, particular attention must be given in all diets to proper supplementation with certain vitamins. The vitamin supplementation is usually even more critical for poultry than for swine, since roughages form proportionately less of their diet.

Even though poultry feeds may contain dehydrated forages, such as alfalfa meal, it is usually necessary to include additional sources of carotene or vitamin A in the rations of birds kept in confinement. Most commercial feed manufacturers usually add enough of the vitamin to com-

pensate for any losses which occur in pelleting or storage of feeds. It is common to use stabilized forms of the vitamin, and also to include an antioxidant such as BHT to prevent its destruction.

Poultry are more efficient than the other large farm animals in the conversion of carotene to vitamin A in the body, being approximately equal to the rat in this respect. Therefore, one U.S.P. unit supplied in the form of carotene, has approximately the same value as an I.U. supplied in the form of vitamin A.

The *minimum* recommendations for vitamin A are 2,000 U.S.P. units of vitamin A value per pound of feed for laying and breeding hens. For starting and growing chicks, the level is 3,000 U.S.P. units of vitamin A value per pound of feed. Rations which are high in xanthophyll, impart a greater yellow color to the yolk of eggs, and the shanks, beak, and body fat of poultry, but such pigments do not have vitamin A value.

Sufficient exposure to direct sunlight, which has not passed through ordinary window glass is effective in meeting the vitamin D requirements of poultry, just as in the case of other livestock. When the birds are not exposed to ultra-violet light it is essential to supply vitamin D in their rations.

The *minimum* requirement for vitamin D commonly recommended is 90 I.C.U. per pound of feed for starting chicks, and 225 I.C.U. for hens. Common commercial practice is to include somewhat greater amounts than the minimum recommended levels in the form of a stabilized vitamin D supplement.

Poultry have an extremely high requirement for riboflavin, and a deficiency of this vitamin is characterized by a paralytic condition of the legs and feet known as "curled toe paralysis" or "nutritional paralysis." Also, hatchability is impaired by a lack of riboflavin in the feed of breeders. Poultry on range have plenty of this important vitamin supplied to them by the fresh green forage, but those kept in confinement must have supplemental sources in their rations.

Rich sources of riboflavin used in poultry rations are milk by-products, dehydrated alfalfa meal, distillers solubles, and fermentation products. Many commercial manufacturers add a synthetic source of this vitamin to their rations. Most commercial feeds contain more than the minimum recommended levels, to guard against destruction in storage, etc.

Although thiamin, pantothenic acid, choline, pyridoxine, folic acid, and biotin are all required by poultry, most rations comprised of natural feedstuffs are adequate in these vitamins. However, pantothenic acid and choline supplements are often added to commercial broiler and hatching-egg rations to insure adequate intakes of these two B-complex vita-

mins. Pantothenic acid is added in the form of calcium pantothenate, and choline is added in the form of choline chloride.

Niacin is required in larger amounts by young and growing chicks than by mature birds. Apparently, some synthesis of niacin occurs in the digestive tract of older birds. Most rations formulated for poultry usually contain sufficient niacin, but those for heavy meat-type broilers are often supplemented with synthetic nicotinic acid.

Vitamin B_{12} is essential for growth of young chicks and for hatchability of eggs. Hens which receive an adequate diet, containing ample vitamin B_{12}, will impart to their chicks a considerable "carry-over" of this vitamin. Hens on diets inadequate in vitamin B_{12} do not impart such an effect, and, unless the chick diet is very adequate in B_{12}, the mortality of the chicks may be high.

Vitamin E is required by poultry to prevent the development of nutritional encephalomalacia or "crazy chick disease" in chicks, and to promote good hatchability and breeding efficiency of mature birds. It is also important in the prevention of exudative diathesis in chicks and poults, and also to prevent the enlarged hock disorder in turkeys. To prevent destruction of this vitamin in commercial rations, an antioxidant such as BHT. is often included.

The requirement of this vitamin probably increases under conditions of stress, and many commercial feeds, such as broiler and "stress" feeds, contain additional amounts of synthetic tocopherols. Ordinary rations usually contain adequate amounts of this vitamin since most cereal grains contain fair quantities, particularly in the oil of the germ. Wheat germ meal and wheat germ oil are particularly good sources of the vitamin. Dehydrated alfalfa meal, and fish meal also contain good amounts. Turkey rations, particularly those for breeders, often include additional amounts of this vitamin, since recent work has demonstrated that many diets comprised of natural feedstuffs are too low in vitamin E for good hatchability (Jensen *et al.* 1956).

"Hemorrhagic disease," a condition in which severe bleeding may occur in any part of the body due to injury, bruising, or even stress; occurs in chicks fed rations deficient in vitamin K. A lack of this vitamin greatly delays the clotting time of the blood, and chicks may even hemorrhage to death if the deficiency or injury is great enough. Usually, 1 to 2 per cent alfalfa meal in the feed, furnishes enough vitamin K to meet all needs.

The requirement for the vitamin is increased under stress and when arsonic acid (a growth stimulant), or sulfaquinoxaline (for coccidiosis control and treatment) are offered to the birds. In such cases it is wise to add supplementary levels of the vitamin in the ration from synthetic

sources. Most commercial broiler feeds, turkey starters, etc. contain sources of vitamin K itself or similar compounds, menadione or sodium bisulfite.

As pointed out previously, chicks and turkey poults usually perform somewhat better if the ration contains sources of the so-called "unidentified growth factors." These unidentified growth factors are not required to any great extent by mature birds for egg production, but breeding birds should be supplied with sources of the unidentified factors in their rations because of the "carry-over" effect to their progeny. Usually, from 2 to $2^1/_2$ per cent of two or more of the various sources of these factors are included in chick and poult rations.

Calf Feeding.—The feeding of calves, particularly dairy calves, is usually discussed under the heading of non-ruminant animals. The reason for this is that rumen function is not well-established until the calf is at least 3 to 4 months of age. Until this time, the calf is essentially a mongastric animal, and its nutrient requirements are similar to them.

Many dairy calves are raised today on the bare minimum of their mother's milk and weaned as early as 10 days to 2 weeks of age from whole milk. Usually calves are removed from the dam at 24 to 48 hours after birth and placed in separate, individual calf stalls approximately 4 by 6 feet in size. It is essential that the young calf receive colostrum soon after birth to protect it against disease and supply vitamin A. Calves are usually pail-fed approximately 1 lb. of whole milk per 10 lbs. of liveweight, with a maximum of 10 to 12 lbs. total daily. It is best to keep the calf somewhat hungry than to overfeed it since overfeeding causes scouring.

When the calf is 10 days to 2 weeks of age it should be offered plenty of the best possible quality hay (preferably, mixed-legume-grass) fed free-choice in a suitable rack. At the same time, it should receive a concentrate mixture. If receiving plenty of whole milk, skim milk or buttermilk it can be fed a simple calf ration or meal free-choice in a suitable feedbox. Such a mixture as corn, 40 parts; oats, 30 parts; wheat bran, 20 parts; and linseed meal, 10 parts; is perfectly satisfactory. Since calves chew grain thoroughly up to an age of 6 to 8 months, whole grains are suitable in such mixtures.

If the calf is to be weaned at an early age or if it is to be on a milk-replacer type of feeding program it should receive a calf starter of more complex formulation containing additional vitamins, minerals, antibiotics and protein of good quality. An example formula for a calf starter of this type is as follows: Cracked yellow corn, 19.475 lbs.; crushed oats, 20.0 lbs.; wheat bran, 15.0 lbs.; linseed meal, 10.0 lbs.; dried skim milk, 5.0 lbs.; soybean oil meal, 14.0 lbs.; cane molasses, 5.0 lbs.; alfalfa meal, 7.0

lbs.; brewers' yeast, 3.0 lbs.; irradiated yeast, 0.025 lb.; ground limestone, 0.50 lb.; steamed bone meal or dicalcium phosphate, 0.50 lb.; iodized salt, 0.50 lb.; and suitable antibiotics.

Because of the high market price for fluid milk in many areas, dairymen often feed only a very limited amount of whole milk to young dairy calves. When a milk-replacer formula is fed, the calf is started on such a formula at about two weeks of age. Milk replacers are usually manufactured by commercial feed companies, since their formulation is necessarily complex. Particular attention must be paid to the antibiotic, vitamin, mineral, protein, and energy content of such feeds. Even the best of such formulas, may not give quite as good results for calves as those which are raised on whole milk during the first few weeks of life. However, economics dictates the use of commercial milk-replacers in most fluid market milk sheds. Very little net difference in the mature weights of cattle are noted even when raised by the different methods. There are many alternative methods of raising calves, and the reader should check standard feeding texts for further information on the various aspects of calf raising (see suggested reference list at end of chapter).

Pet Foods.—The chief pet foods of concern to most commercial manufacturers are those for cats and dogs. There is a lack of good information with respect to the requirements of both dogs and cats. An excellent starting point for the development of feeds for dogs is the report of the subcommittee of Canine Nutrition of the National Research Council, entitled "Nutrient Requirements of Dogs" (Robinson *et al.* 1953).

Since both dogs and cats are mongastric animals, their nutrient requirements are similar to both swine and poultry in many respects. It is possible to develop dry feeds which apparently do a fine job in many instances. However, palatability of rations still remains a great problem in the formulation of dry dog and cat foods, and many owners will continue to feed their pets at least partly on a meat or table scrap basis along with a dry cereal based food.

Such a formula as the one on page 688 supplies the dog with protein of ample quantity and quality, the essential amino acids, vitamins, minerals, and energy. Many variations are possible in developing ratios both for cats and dogs which still meet their nutrient requirements and are usually acceptable from a palatability standpoint.

When dry dog foods alone are fed, it may be somewhat preferable to place the dogs on a self-feeding basis than attempt to hand-feed. Wetting or moistening the food sometimes aids in creating more acceptable rations.

It may be impossible to feed pampered and tempermental pet cats on dry feeds alone, after they have become accustomed to canned or fresh

meat-based foods. Many dry dog foods when mixed with raw meat, and moistened with milk or water are acceptable to cats. It is particularly important in cat rations to insure adequate thiamin, particularly if rough fish is included in the diet.

An example of a satisfactory dry dog food formula is as follows:

Meat and bone meal, 55 per cent protein	8.00
Fish meal, 60 per cent protein	5.00
Soybean oil meal	12.00
Wheat germ oil meal	8.00
Dried skim milk	4.00
Wheat, ground	10.00
Oat groats	20.00
Corn, ground	11.23
Ground-hulled barley	10.00
Wheat bran	4.00
Fat, edible	2.00
Steamed bone meal	2.00
Dried brewers yeast	2.00
Dried fermentation solubles	1.00
Iodized salt	0.50
Vitamin A and D feeding oil (2250 U.S.P.A., 400 ADAC D/gm.)	0.25
Iron oxide	0.02

ADDITIVES IMPORTANT IN FEED FORMULATION

Many modern feed formulas make use of additives which produce certain effects in the ration. These additives are of many types and only a brief classification can be made of them under use headings.

I. Additives for the Promotion of Growth

A. Antibiotics:

1. Chlortetracycline
2. Oxytetracycline
3. Penicillin
4. Bacitracin
5. Aterrimin

B. Chemicals

1. Arsonics:
    a) Arsanilic acid
    b) 3-nitro-4-hydroxy-phenylarsonic acid
    c) Sodium arsanilate
2. Furazolidone
3. Trimethylalkylammonium stearate

C. Hormones
  1. Diethylstilbestrol
  2. Dienestrol diacetate
D. Tranquilizers

II. Compounds Added to the Feed for Disease Prevention and/or Treatment

A. Antibiotics
  1. Chlortetracycline
  2. Oxytetracycline
  3. Penicillin
  4. Bacitracin
  5. Streptromycin
  6. Erythromycin
B. Arsonics
C. Nitrofurans, particularly furazolidone
D. Amino nitrothiazole
E. Trimethylalkylammonium stearate
F. Nithiazide

III. Coccidiostats

A. Sulfas
  1. Sulfaquinoxaline
  2. Sulfaguanidine
  3. Sulfamethazine
B. Nicarbazin
C. Nitrophenide
D. Nitrofurazone
E. Bifuran (combination of nitrofurazone and furazolidone)
F. Glycamide
G. Unistat
H. Polystat
I. Nitrosal
J. Trithiadol
K. Arsenosobenzene

IV. Medicaments or Additives Used for Special Purposes

A. For the prevention of ketosis:
  1. Sodium propionate
  2. Calcium lactate, or combinations of calcium lactate and other compounds
  3. Sodium acetate
B. For the prevention of bloat:
  1. Methyl silicone

2. Tetracycline
3. Penicillin

C. For the prevention of milk fever:
1. Therapeutic levels of vitamin D

D. To stimulate milk production in both dairy cows and brood sows:
1. Thyroprotein

V. Compounds Added to the Feed for Internal Parasite Control

A. Nicotine sulfate
B. Phenothizine
C. Sodium fluoride
D. Cadmium compounds
E. Piperazine salts
F. Dibutyltin dilaurate
G. Hygromycin

VI. Compounds Added to the Feed for the Prevention of Oxidation of Fat Soluble Vitamins and Preservation of Feed Quality, and to Serve as Anti-Oxidants

A. BHT
B. BHA
C. Santoquin
D. D.P.P.D. (compound formerly used but now outlawed for use in feeds by the Federal Food and Drug Administration)

VII. Other Additives to Feeds of Unclassified or Unknown Value

A. Surfactants
B. Bentonite
C. Enzymes
D. Dried rumen cultures
E. Various flavors

One can clearly see from the foregoing classification that the field of feed formulation and nutrition of farm animals has become extremely complex and poorly understood by many people. The development of medicated feeds and special purpose feeds has placed an extra burden on feed manufacturers, and has necessitated close working relationships with allied fields such as chemical manufacturers, pharmaceutical houses, the federal government and veterinarians. The subject is constantly expanding and is in a dynamic state of flux and transitional change.

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R. T. Cotton

Effects and Detection of Insect and Rodent Infestation of Cereals

INTRODUCTION

Supplies of grain and its products which are improperly stored, are vulnerable to the attack of many species of insects and rodents. Such stores supply food and harborage to these pests whose insignificant size and furtive manners often prevent their discovery until large losses are sustained.

The husbandman has become accustomed to the annual toll exacted by these pests, and in many parts of the world fails to provide storage facilities adequate to protect his crops from their depredations.

Losses to the world production of cereal grains, pulses and oil seeds caused by insects, rodents and mold fungi were the subject of a survey conducted by the United Nations Food and Agricultural Organization in 1947. In summarizing the results of this survey, Steven S. Easter, Entomologist for the F.A.O., stated that the losses from 27 countries ranged from no loss to 54 per cent of the production of cereals, wheat, corn, barley, oats and rye. Of the total annual production, plus excess of imports over exports of 323,923,900 metric tons of these cereals the aggregate loss was 25,750,000 metric tons, or a trifle under 8 per cent. A number of these countries indicated that these figures did not include losses of grain in farm storage. It was concluded that if these unknown losses during farm storage were added to the estimate, the total would exceed 10 per cent. (Cotton 1948).

The losses to grains and pulses sustained by some of the Latin American countries were studied by a working party of the United Nations for the period 1947 to 1949 (Anon. 1950). Estimated losses of corn, rice and pulses during that period were Uruguay 14 per cent, Mexico 15–25 per cent, El Salvador and Guatemala 25 per cent, Nicaragua 30 per cent, Costa Rica 45 per cent, Haiti 47 per cent and Honduras 50 per cent.

In the United States, losses from grain pests are not so great as in some parts of the world where climatic conditions and facilities for handling and storing cereal grains are less favorable. Nevertheless, the annual losses to our cereal grains and their products have been estimated to be from 200 million to 600 million dollars from insect attack and an even greater amount for rodents.

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In addition to the direct loss to our cereal foods from the quantity consumed by these pests, there are losses resulting from contamination. Little attention was paid to the effects of contamination by insects and rodents until the passage and enforcement of the Food Laws of 1906 and 1938 which banned from the channels of interstate commerce, food which, "consists in whole or in part of any filthy, putrid, or decomposed substance," and provided that they must not be, "prepared, packed or held under unsanitary conditions whereby they may have become contaminated with filth."

THE INSECT PROBLEM

General Considerations

Grain and grain products constitute the natural food of a group of insects known as stored product pests. Several hundred different species of insects are found associated with stored grains or their products; however, only a few are primary pests capable of destroying large quantities of grain by their feeding. The presence of any species of insect in our food supplies is undesirable and classifies it as a pest.

Many of these insect pests of stored grain are of tropical or subtropical origin. They thrive in warm, humid climates, but do not do well in either dry or cold environments. These factors therefore, largely determine their relative abundance and destructiveness in the various grain growing regions of the United States. In the extreme South insects breed with little interruption the year around, whereas in the Northern States severe winters greatly limit their abundance.

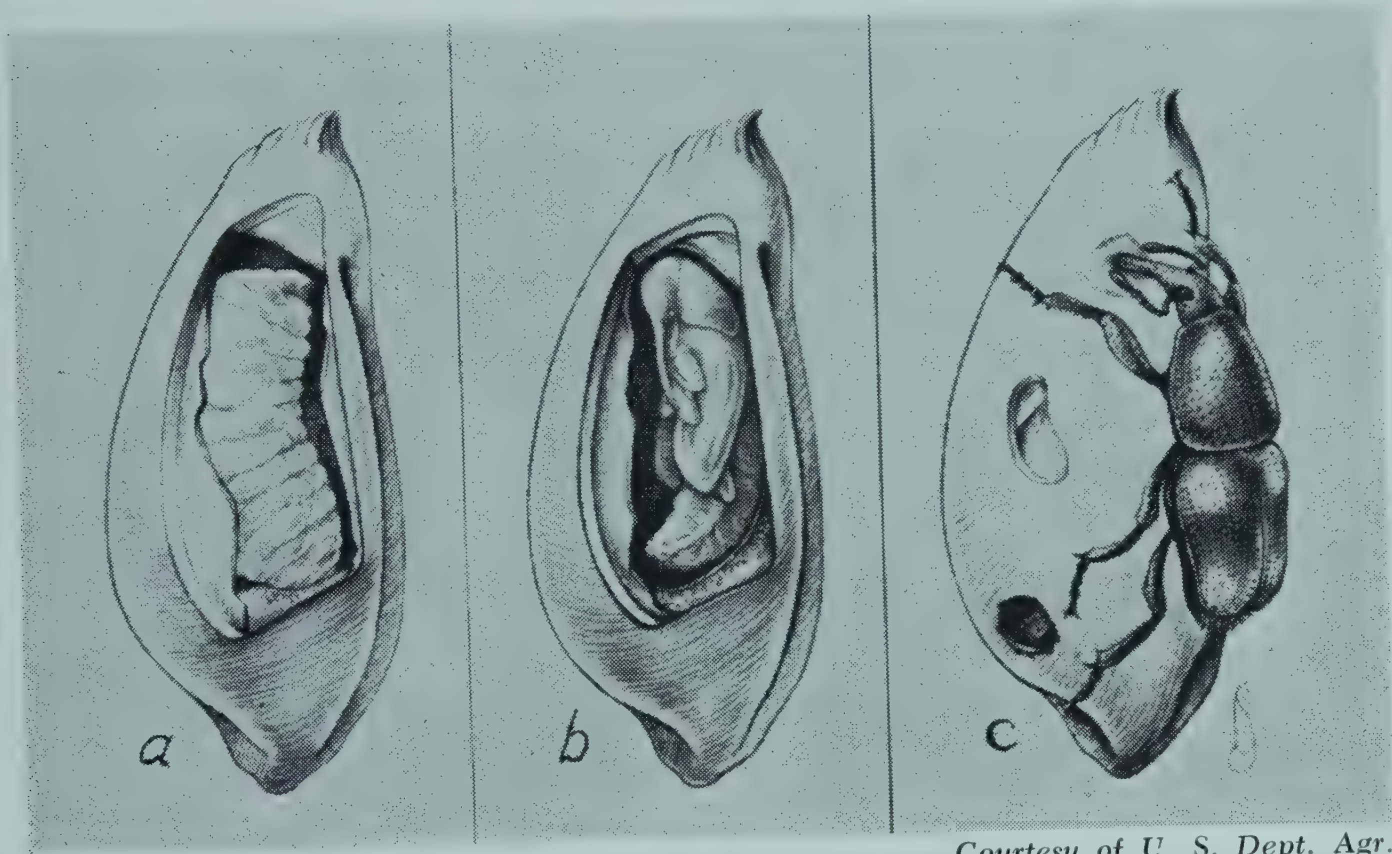
Early History

Before the discovery of America by Columbus, corn served as the chief grain food of the American Indian. In those early days the stores of corn were singularly free from insect attack. A few of the minor pests of stored grain are indigenous to the American Continent, but it is doubtful whether any of them ever caused serious damage to grain. Many of them originally fed on edible tubers, and with few exceptions are thought to have originated in South or Central America. Few of them are found damaging stored grain anywhere in North America except in the extreme South.

The insects that really cause serious damage to our stored grains originated in those parts of the world where wheat, barley and rice were the principal grain foods. They were introduced into America by the early explorers and settlers. Through the avenues of international commerce the insect pests of stored grains have now been distributed throughout

the world so that those species which have been able to adapt themselves to the varied climatic conditions of the world can be said to be truly cosmopolitan.

Many of the common pests of stored grain have been known to man for thousands of years. Plautus referred to one of the grain weevils in 196 B.C. as the Curculio, and archaeologists exploring the tombs of Egypt and other ancient civilizations have unearthed specimens of several common species in jars of grain originally placed in the tombs about 2,500 B.C.



Courtesy of U. S. Dept. Agr.

FIG. 159. THE RICE WEEVIL (*Sitophilus oryza*)

A. Larva, B. Pupa, C. Adult.

Common Grain Pests and Their Habits

The weevil referred to by Plautus is thought to be the granary weevil (*Sitophilus granarius* (L.)) which was first described and named by Linnaeus in 1759. This weevil and its close relative, the rice weevil (*Sitophilus oryza* (L.)), are reddish-brown beetles (Fig. 159), about one-eighth inch long. Their mouth parts are prolonged into a more or less elongated snout, which enables them to bore into kernels of grain for food and to excavate holes in which the female weevils deposit their eggs. The eggs hatch in a few days into grubs which complete their development to the weevil or adult stage, entirely within the kernels, in from 3 to 4 weeks during warm weather. The size of the weevil depends to a considerable extent on the size of the kernel of grain. In small grains

such as milo it will be small in size, but in corn it will attain its maximum stature. The contents of small grains are almost completely devoured by one average weevil grub during its development from egg to adult, whereas a kernel of corn will provide food for several weevils. The fact that these weevils spend their grub stage entirely concealed within the kernels of grain explains why grain, seemingly in good condition, may suddenly be found swarming with weevils.

Other beetles which have the habit of spending their larval life concealed within the kernels of grain are: the broad nosed grain weevil (*Caulophilus latinasus* (Say)), and the coffee-bean weevil (*Araecerus fasciculatus* (De Geer)). The lesser grain borer (*Rhyzopertha dominica* (F.)), Fig. 160, has similar habits; however, its grubs are also capable of living outside the grain kernels in the flour or grain dust made by the feeding beetles.

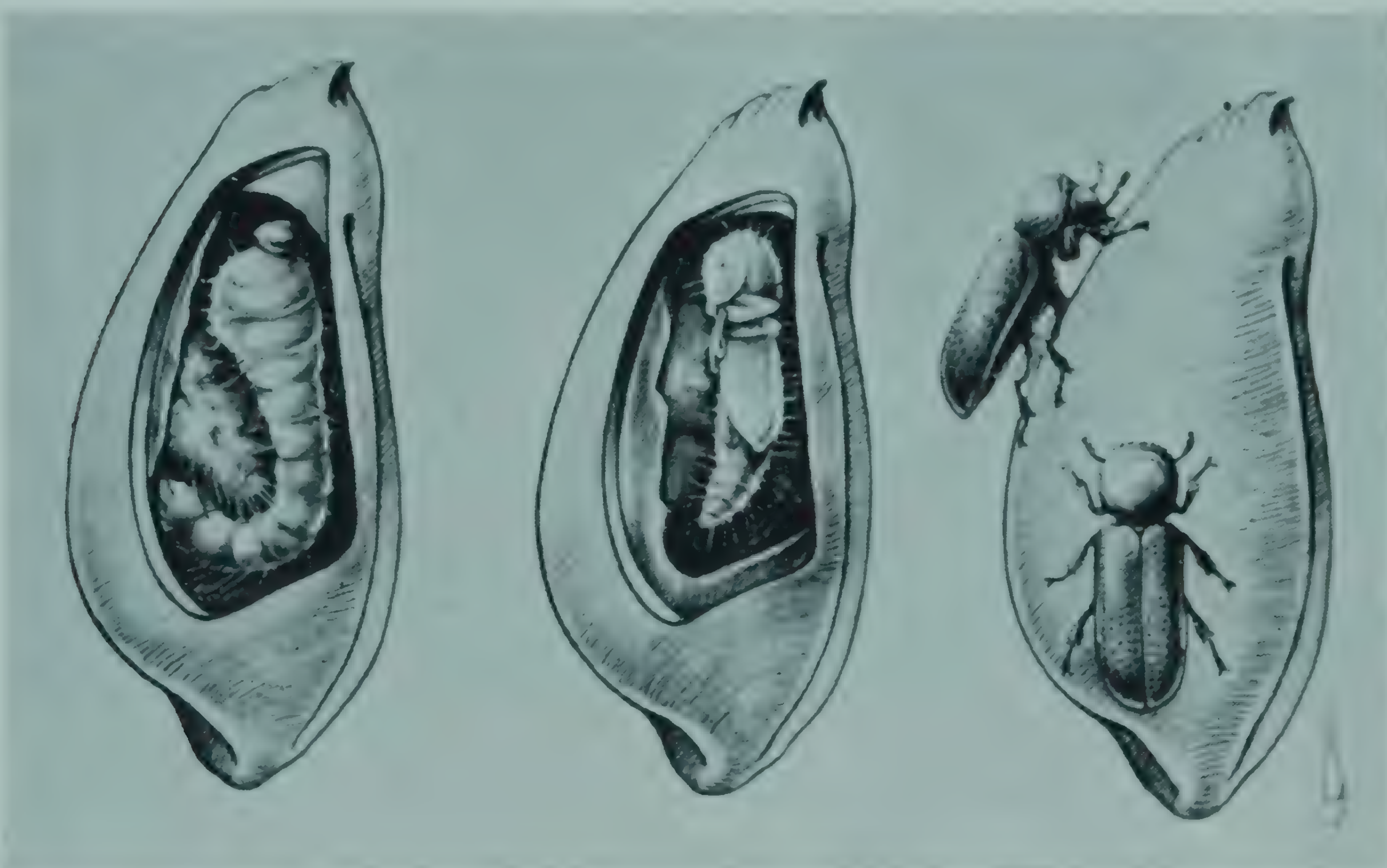


FIG. 160. THE LESSER GRAIN BORER (*Rhyzopertha dominica* (F.)) IN WHEAT

One other insect that spends its larval life within kernels of grain is the Angoumois grain moth (*Sitotroga cerealella* (Oliv.)). It is second in importance only to the rice weevil in its ability to destroy grain (Fig. 161).

A large group of beetles which feed on grain dust, broken kernels, germ or the softer portions of grain are referred to as bran beetles. Their mouthparts are not prolonged into beaks and they are unable to cause the feeding damage to sound grain so characteristic of the grain weevils. The most important of these are the so-called flour beetles (*Tribolium*

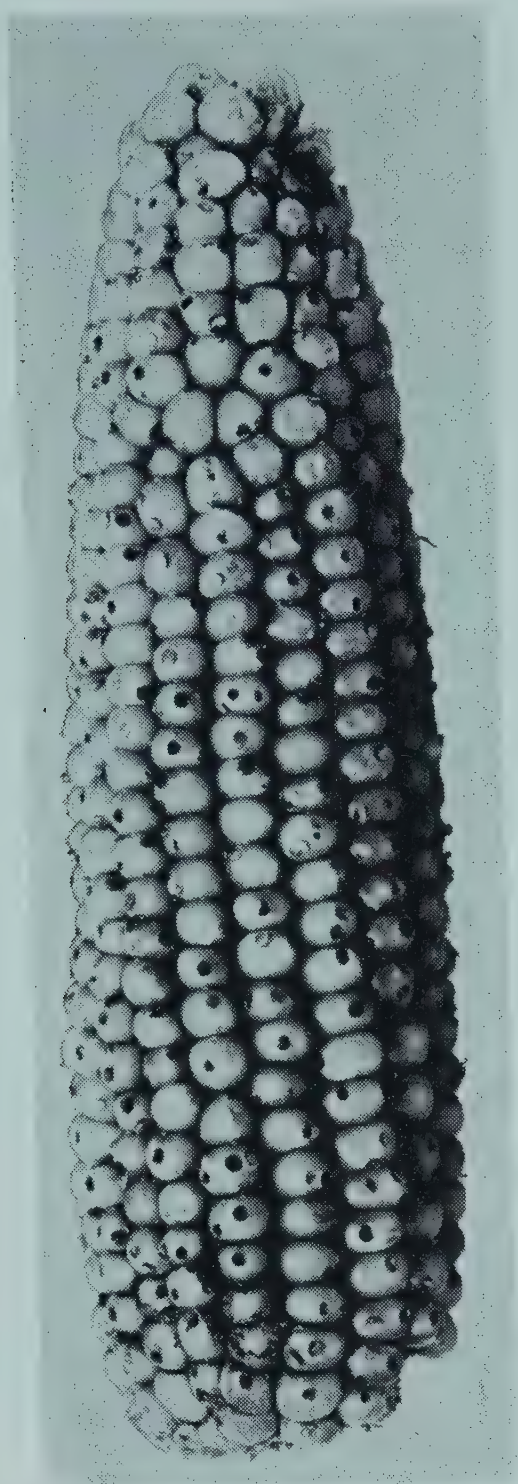


Fig. 161. Ear of Corn with Practically all Kernels Destroyed by the Angoumois Grain Moth

Courtesy of U. S. Dept. Agr.

confusum (Duv.), Fig. 162, and *T. castaneum* (Hbst)). They are the chief pests of milled cereal products.

The bran beetles as a group have the habit of laying their eggs indiscriminately in or near grain or its milled products. Their larvae are for the most part free living, although larvae of the flour beetle, the Cadelle and the flat grain beetle occasionally burrow into kernels of grain. It is characteristic of most of these beetles that generations are short, the rate of reproduction high and individuals are long lived. Gray (1948) has calculated that the progeny of a single pair of confused flour beetles could exceed a million in 150 days under favorable conditions.

A number of moths are general feeders on grain and its products. The most important moth pest of grain in North America is the Indian meal moth (*Plodia interpunctella* (Hbn.)) Fig. 163, whereas the Mediterra-

Courtesy of U. S. Dept. Agr.

FIG. 162. PUPAE, ADULTS AND LARVAE OF THE CONFUSED FLOUR BEETLE (*Tribolium confusum* (Dur.))

nean flour moth (*Anagasta kühniella* (Zell.)) is most troublesome as a pest of milled products in flour mills.

A detailed account of the life history and habits of the common pests of stored grain and milled cereals and their control has been published by Cotton (1956).

In the commercial corn growing area of Illinois, Iowa, Nebraska, Minnesota and South Dakota, the six species most commonly found in stored shelled corn and constituting more than 98 per cent of the insect population are the saw-toothed grain beetle (*Oryzaephilus surinamensis* (L.)), flat grain beetle (*Laemophloeus* (spp.)), red flour beetle, the foreign grain beetle (*Ahasverus advena* (Waltl.)), larger black flour beetle (*Cynaeus angustus* (Lec.)) and the hairy fungus beetle (*Typhaea stercorea* (L.)). The first three species comprise the greater portion of the insect population. In the South, where field infestation is common, the rice weevil is by far the most abundant species in stored corn.

In the Great Plains hard winter wheat region, seven species constitute more than 90 per cent of the insect population of wheat in farm storage: the flat grain beetle, saw-toothed grain beetle, lesser grain borer, red flour beetle, long-headed flour beetle (*Latheticus oryzae* (Waterh.)), Cadelle (*Tenebroides mauritanicus* (L.)), and the rice weevil. Their

Courtesy of U. S. Dept. Agr.

FIG. 163. THE INDIAN MEAL MOTH (*Plodia interpunctella* Hbn.) INFESTING EAR OF CORN

relative abundance varies with climatic conditions. In the northern parts of the region, the hardier species, the flat grain beetle and the saw-toothed grain beetle, predominate. In the southern part, the lesser grain borer and the rice weevil become increasingly abundant.

Along the Eastern Seaboard the Angoumois grain moth is occasionally one of the common pests of stored wheat, although ordinarily the flat grain beetle and the rice weevil are the most abundant species there. Found in greatest numbers in rough rice in storage are the Angoumois grain moth, rice weevil, flat grain beetle, lesser grain borer and the red flour beetle.

Moths that attack grain are not the most abundant species; however, they occasionally appear in tremendous numbers wherever grain is stored. They confine their activities largely to the surface grain, and their cater-

pillars spin silken threads which mat the kernels together and form a silken web over the tops of the bins. The Indian meal moth, the chief offender in the United States, attacks all types of grain. The almond moth (*Ephestia cautella* (Walk.)) is at times abundant in stored rice and in shelled corn in the South.

Field Infestation

Many of the insect pests of stored grain are to be found living in the field in regions where climatic conditions are favorable for their existence. They breed in the seeds of many wild and cultivated plants, and in the South and Central States attack some types of grain as it begins to ripen in the field.

Small grains such as wheat, barley, rye, oats and rice are protected by the glume or husk which surrounds the kernel. Field infestation of small grains by the rice weevil is rare (Cotton *et al.* 1953), however, the Angoumois grain moth is quite capable of infesting small grains in the field.

Corn and sorghum grain are attacked by a number of insects in the field. In the case of corn, the tips of the ears are frequently exposed, and where the shuck is damaged by the corn earworm larva, it is easy for weevils to reach the kernels. Heavy flights of the rice weevil from infested corn cribs and other breeding areas occur in the South, and it is not unusual to find cornfields in Georgia, Florida, Alabama, Mississippi, Louisiana and Texas with almost every ear infested in the field before harvest.

Floyd and Powell (1958) state that in Louisiana in 1955, infestation records made in the field at the time of harvest or immediately thereafter showed that the average kernel damage or infestation for the state was 8.67 per cent, with 37 per cent of the ears infested. Corn from this same cribs in the following May 1956 after 6 to 7 months storage on the farm averaged 13.5 per cent kernel damage, and in August 21.6 per cent. The initial damage was caused by the rice weevil; however, infestations of the Angoumois grain moth, which occurred during storage, added to the loss.

Infestation in Storage

In the commercial corn growing area, field infestation by insects is slight except in southern Illinois, Indiana, Missouri and Kansas. Storage of corn on the ear in slat cribs during the first winter of storage on the farm in this region results in the destruction of most insect life as a result of exposure to the killing frosts. It is not until the corn is shelled and stored as shelled grain that serious damage from insect attack is likely except during years when outbreaks of the Angoumois grain moth follow a succession of mild winters.

Insect infestation of small grains and shelled corn occurs during storage on the farm. Insects concealed in the woodwork of bins or migrating from other lots of stored grain or feed on the farm account for the origin of much of this infestation.

The rapid build up of the insect population in untreated bins of grain during the summer months is indicated by studies conducted in Kansas during 1946 to 1950 (Cotton *et al.* 1953 and Cotton 1949). The average adult insect population of bins of wheat during September of these years averaged from 735,480 to 3,023,640 per 1000 bushels. During the period from July to November, the average adult insect population of wheat bins in farm storage increased from 40.8 insects per 1000 gm. (about one quart) in July, to 129.1 per 1000 gm. in October. More than 100,000,000 bushels of wheat were in farm storage in Kansas during that period, and a simple calculation shows that the insect population of that wheat in October exceeded 350 billions. These insects destroyed between 1 and 2 per cent of the wheat per month during the period July to November. A conservative estimate of the loss in 1947 of wheat stored on farms in Kansas alone would be 5,000,000 bushels.

Feeding Losses

The insect pests of stored grain are capable of devouring their own weight and more of food each week, and their larvae consume many times their weight during the period of their development. According to Richards (1947), a rice weevil larva turns about 14 mg. of a kernel of wheat into carbon dioxide and water, produces 14 mg. of excrement, and consumes about two-thirds of the endosperm during its development.

White (1953) also studied the loss in weight of wheat caused by the developing rice weevil. He exposed wheat kernels to infestation by the rice weevil, screened out the adult weevils, determined the percentage of infested kernels by use of X-ray radiography, and weighed the infested samples each week for seven weeks or until emergence was complete. He found a steady loss in weight each week as a result of the oxidation of the endosperm consumed by the feeding weevil grubs.

In samples which contained 30 per cent of infested kernels the loss in weight for the first four weeks was about four per cent, although no infestation was visible. At the end of seven weeks, when emergence was complete, the loss was ten per cent of the weight of the entire sample. From these figures it has been calculated that each per cent of infested kernels in a sample denotes a loss in weight of approximately 0.3 per cent from larval feeding. Neither the weight of larval excrement left in the kernel nor the loss in weight that would have been caused by the feeding of the adult weevils, had they been left in the wheat, was taken into con-

sideration. These figures enable one to calculate roughly the amount of damage already sustained from an infestation of the rice weevil.

Crombie (1944) found that the saw-toothed grain beetle consumed 6.75 mg. of food per week as a larva and from 2.0 to 2.5 mg. per week as an adult, whereas the confused flour bettle consumed 26 mg. per week as a larva and from 2.0 to 3.0 mg. per week as an adult. Richards and Waloff (1946), reported that one larva of a grain-feeding moth (*Ephestia cautella* (Hbn.)) consumed the embryos of about 48 kernels of wheat during its development.

Other Losses Resulting From Infestation

In addition to the loss from grain actually consumed, the consequences resulting from the presence of insect forms that live and feed within the kernels of infested grain are of paramount importance. These internal feeding insects and their contamination cannot be entirely removed by any practical known method. Studies by Harris *et al.* (1952) showed that in the case of wheat the effect of cleaning on the reduction of insect contamination varied from mill to mill. However, although it varied from none to more than 50 per cent, the average reduction was about one-third.

In the milling process insect bodies and their excrement within the kernels of grain are milled along with the grain, so that flour made from infested grain becomes contaminated with insect fragments. For this reason grain that becomes materially infested with the common insect pests of these commodities is unfit for processing into human food. In general, it has been found by millers that wheat with more than 0.5 per cent of infested kernels is undesirable for milling. For domestic flour production some mills will not use wheats for their mill mixes that contain more than 8 internal insect forms per 100 gm.

Insects cause other kinds of damage to stored grain. Many species feed almost entirely on the germ of the grain so that its viability is reduced and much larger quantities of infested than uninfested grain must be used for seed. From the viewpoint of food value, the most nutritious portions of grain are preferred by insects and are eaten first.

The mere presence of a living, active, population of insects in a bulk of of grain causes heat to accumulate as a result of their metabolic processes. When the surface grain cools, water vapor is translocated to it from the area of the heating grain and condenses in the cooler grain. In extreme cases, the surface grain rots, moulds or begins to sprout. Although the damage does not usually extend more than two feet below the surface, the entire grain mass may be contaminated with the musty, rotten surface grain when the bin is emptied, so that it is all graded as "sample musty," and must be offered for sale at a discount.

A lowering of the grade of grain is often caused by off-odors or insect damage and the milling quality and milling yield of infested grain is reduced. In a study by Walkden (1951), the damage caused by insects to farm stored wheat during five months of storage was assessed in four untreated bins in which the wheat was weighed into and out of storage and graded for quality as shown in Table 141.

TABLE 141

CHANGES IN CONDITION OF FARM STORED WHEAT OVER 5-MONTH PERIOD AS A RESULT OF INSECT INFESTATION[1]

Original Test Weight Lbs. per Bushel	Original Grade	Insect Damage Per cent	Test Wt. at Delivery Lbs. per Bu.	Grade at Delivery	Discount per Bu. Cents[2]
60	1 HW	3	58	2 HW	1
58	2 HW	3	56	3 HW	2
58	2 HW	10	52	4 HW Weevily	5–10
58	2 HW	14	50	Sample HW musty, weevily	20–30

[1] Walkden (1951).
[2] Based on No. 1 hard winter wheat at $1.96 per bushel.

The reduction in milling yield of wheat due to infestation was described by Burquest (1955) in an experiment on the effect of the number of internal insect forms in wheat on the milling yield. He reached the conclusion that millers will encounter difficulty with an ash in flours milled from infested wheat. He found what appeared to be a direct correlation between insect fragments in flour and the ash content if the degree of infestation exceeds 7 to 12 internal forms per 100-gm. sample.

When wheat containing sufficiently high degrees of internal infestation is milled, increases of ash in certain streams require their diversion to lower grades of flour resulting in a loss of patent or higher grade flour. With wheat containing 12 internal forms per 100 gm. there was a loss of 1.5 per cent of patent flour. A mill grinding 15,000 bushels of wheat per day would lose 135 cwt. of patent flour with a corresponding increase in the lower grades of flour. He concluded that the milling of infested wheat even at a low level is expensive. He found that wheat which becomes infested to a degree of 7 to 12 internal forms per 100 gm. suffers a 2 per cent loss of weight over a 60-day period. In wheat containing 20 internal forms, the test weight and grade was seriously affected.

INSECT CONTAMINATION IN WHEAT AND WHEAT FLOUR

Insect contamination in flour, corn meal, or other milled cereal products is a matter of considerable concern to the miller, processor and baker. The filth load in such products can be accurately determined by analytical methods, and if it is excessive, such products are subject to seizure.

The control of insect infestation in mills, processing plants and bakeries has advanced to such a high level by modern methods of sanitation and the judicious use of fumigants and newly developed insecticides that insect populations are held to such low levels that contamination of milled cereals or bakery products in the modern plant is insignificant from this source.

A cooperative study between industry and the Food and Drug Administration on insect and rodent contamination of wheat and wheat flour (Harris *et al.* 1952) showed that the major source of contamination of flour is the wheat in market channels.

In the course of this study, samples of wheat and flour were taken from 16 mills, located in representative parts of the country, at regular intervals over a period of one year to determine the relationship of insect infestation in wheat to the insect fragment count in flour made from it. Insect and rodent contamination in market wheat was also determined from the examination of 1410 samples taken from 109 mills over a similar period.

TABLE 142

RELATIONSHIP BETWEEN INSECT FRAGMENTS IN THE FLOUR TO INSECTS IN THE CLEANED AND UNCLEANED WHEAT[1]

Insect Frag. Per 50 Gm. Flour Range	Number of Samples	Cumulative Per cent of Total	Insects by Cracking 100 Gm. Wheat			
			Uncleaned		Cleaned	
			Range	Average	Range	Average
0	18	6.8	0– 1	0.06	0– 0	0.00
1–5	77	35.7	0– 3	0.31	0– 2	0.16
6–10	29	46.6	0– 4	0.86	0– 2	0.48
11–15	14	51.9	0– 6	1.50	0– 1	0.50
16–20	10	55.7	1– 5	2.60	0– 4	1.10
21–30	31	67.3	0–10	3.26	0–11	2.29
31–40	22	75.6	1–13	4.77	0–10	3.59
41–50	13	80.5	2–12	6.31	2– 9	4.77
51–60	8	83.5	3–13	7.12	3– 9	4.88
61–80	16	89.5	4–14	8.50	3–12	5.38
81–100	5	91.4	2–13	9.80	5–11	6.60
101–150	10	95.2	4–34	10.80	3–31	8.50
151 and Over[2]	13	100.0	4–78	30.77	4–58	23.38
Total or average[3]	266			4.2		3.0

[1] Harris *et al.* (1952).
[2] Actual counts: 156, 191, 204, 205, 212, 229, 242, 261, 342, 365, 748, 774, 1022.
[3] Over-all averages; not taken from figures in table.

The close relationship between the number of insect fragments in flour and the number of insects in the wheat used for milling is shown by the data of Table 142, taken from the report.

The insect fragment counts are listed as ranges of increasing magnitude. The number of samples in each range is shown, the range in number of insects and the average number of insects found in the uncleaned wheat.

TABLE 143

DISTRIBUTION OF SAMPLES IN RELATION TO THE NUMBER OF INSECTS (1000 GM. CRACKING TEST) INCLUDING BREAKDOWN BY TYPE OF WHEAT[1]

Insects by Cracking Test	Number of Samples	Per cent of Samples	Type of Wheat: HRS No.	HRS Per cent[2]	HRW No.	HRW Per cent[2]	SRW No.	SRW Per cent[2]	White No.	White Per cent[2]
0	676	47.9	236	79.3	268	34.8	54	30.5	107	76.4
1	173	12.3	30	10.1	91	11.8	31	17.5	17	12.2
2	111	7.9	13	4.4	70	9.1	22	12.4	4	3.0
3	70	5.0	7	2.4	56	7.3	5	2.8	1	0.7
4	71	5.0	6	2.0	52	6.8	10	5.6	2	1.4
5	51	3.6	1	0.3	42	5.5	4	2.3	1	0.7
6	40	2.8	1	0.3	32	4.2	5	2.8	..	..
7	32	2.3	..	..	24	3.1	7	3.9	1	0.7
8	23	1.6	1	0.3	18	2.3	4	2.3	..	..
9	27	1.9	1	0.3	24	3.1	1	0.6	1	0.7
10	22	1.6	1	0.3	19	2.5	2	1.1	..	..
11	12	0.8	..	..	7	0.9	4	2.3	1	0.7
12	14	1.0	..	..	11	1.4	2	1.1	1	0.7
13	10	0.7	..	..	7	0.9	2	1.1	1	0.7
14	7	0.5	..	..	6	0.9	1	0.6	..	..
15	7	0.5	..	..	6	0.8	1	0.6	..	..
16–50	54	3.8	1	0.3	31	4.0	18	10.2	3	2.1
51–100	8	0.6	..	..	5	0.6	3	1.7	..	..
Over 100[3]	3	0.2	..	..	1	0.1	2	0.6	..	..
Totals	1411	100.0	298	100.0	770	100.0	178	100.0	140	100.0

[1] Harris *et al.* (1952).
[2] Per cent of each particular type having given level of infestation.
[3] Actual counts: 277, 125, 107.

The authors conclude that of the total of 266 flour samples examined 35.7 per cent contained 5 or less, 55.7 per cent contained 20 or less and 80.5 per cent contained 50 or less insect fragments per 50 gm. of flour. About nine per cent of the samples contained more than 100 insect fragments per 50 gm. The average insect fragment count for all flour samples was 41.3 per 50 gm. The average number of insects per 100 gm. of both cleaned and uncleaned wheat increased progressively and in a fairly regular manner with the increase of insect fragment counts.

As a result of the survey of 1410 samples of wheat taken from 109 mills over a period of one year, the authors reported that only 47.9 per cent of wheat samples reaching the mills showed no internal insect infestation by the cracking flotation test. Insect infestation in wheat tended to be lower in the West, Northwest, Intermountain and Northern States, or in areas where the the wheat is predominantly hard red spring or white wheat. The insect infestation level was higher in the hard red winter wheat of the Central Plains States and still higher in the soft red winter wheat from the Midwestern and Eastern States. The range of insect infestation found in the samples and the relationship between the type of wheat and insect infestation is shown by the data of Table 143.

There was a decrease in insect infestation in market wheat from May to September with the marketing of the new crop as would be expected, followed by a rise in September which continued through the winter months and reflected the build-up of infestation during storage.

Insect infestation in wheat was found to increase as the wheat moved from the farm to the terminal elevator, reaching its highest peak in the terminal elevators.

INSECT CONTAMINATION OF MARKET CORN AND CORN MEAL

As a result of the Food and Drug Administration survey concerning insect contamination of market corn and its relation to contamination in corn meal (Harris *et al.* 1953), studies were made of the insect contamination in corn received at mills and terminal elevators over a 12-month period, and of the contamination in corn meal made at eight different mills.

The conclusions reached were that, "substantial proportions of both white and yellow corn being purchased by corn millers are contaminated with internal feeding insects. Only 55 per cent showed no insects per 100 gm."

> "For all samples, there was an average reduction of about 25 per cent in the number of internal insects by mill cleaning procedures as shown by the cracking-flotation test before and after cleaning."
>
> "The insect fragment count of bolted corn meal is closely related to the number of whole insects in the corn. The ratio of fragments in bolted meal to whole insects in the cleaned corn was 12.5:1."
>
> "The incidence of insect infestation in white corn is significantly higher than in yellow corn. Insect contamination in corn reaches a peak toward the end of the crop year (October)."

It has been conclusively shown that contamination of grain supplies used in milling is responsible for a large proportion of the contamination in milled cereal products. It follows that contamination in milled cereal products is responsible for contamination in flour mixes, baby foods, bakery goods and specialty products in which these components are used. It is essential therefore to be sure of the quality of the raw products used in the preparation of food intended for human use if adulteration of the product is to be prevented.

The Food, Drug and Cosmetic Act (1939) provides no tolerances for filth in food products; however, the courts have consistently held that the law should be interpreted in its common or usual sense, recognizing that there may be unavoidable minute amounts of contamination present that do not render the product violative.

A study of the insect fragment count of flour supplied by a number of

mills to a large baking concern from 1948 to 1951 was reported by Farrell and Milner (1952). From data supplied by the baking concern they found that the average insect fragment count of flours supplied in 1948 was consistently above 100 per pound from all sources, whereas by 1950 the average was well below 100 per pound.

Milner (1958) states that flour currently being supplied to the baking industry is now much freer from insect fragment contamination and contains on the average less than 50 insect fragments per pound.

THE DETECTION OF INSECT INFESTATION

Introduction

Reliable means to evaluate the wholesomeness of grain and milled cereal products are available. They consist of a combination of rigid inspection and micro-analytical methods. These procedures should be used to head off trouble. In the case of grain, simple tests can be applied by field men to determine the condition of stocks of bulk grain before they are purchased.

In most cases where grain contains an appreciable insect infestation, there will be a large enough percentage of kernels with insect emergence holes to give a rough indication of the actual quantity of infestation present. Infestation in grain usually becomes apparent to the naked eye when the level of internal infestation reaches 3 insects per 100 gm. This is far below the one per cent level set by the Food and Drug Administration as warranting seizure. The presence of free living insects in the grain can easily be determined by sieving.

Many methods of estimating the extent of internal insect infestation in grain have been suggested. Only a few are currently in use; however, it seems desirable to describe a few of the methods which have been proposed during recent years.

The Carbon Dioxide Test

Howe and Oxley (1944 and 1952) proposed a method based on a measurement of the total metabolism of the sample to be examined. By measuring the quantity of carbon dioxide produced in a given sample of grain by the metabolism of insects, of the grain itself or of microorganisms, a direct measure of the suitability of the grain for further storage is obtained.

The grain sample should be aerated, sieved to remove free living insects, and the moisture content determined. The grain sample is then placed in an airtight flask or glass bottle of any convenient size which it must completely fill. The container is then sealed and incubated for 24

hours at 77° F. The glass bottles should be closed with rubber stoppers and provided with a tube of small bore for withdrawing an air sample at the end of the incubation period.

At the end of the 24-hour incubation period a gas sample is taken and the per cent concentration of carbon dioxide determined with a suitable apparatus.

If the carbon dioxide concentration exceeds one per cent at the end of that period, it is certain that a potentially dangerous insect infestation is present. Uninfested grain of less than 15 per cent moisture content may produce up to 0.25 per cent CO_2, so that a figure up to 0.3 per cent may represent insect-free grain if the moisture content of the grain is 14 per cent, or above. If the moisture content of the grain is below 14 per cent, such a reading would indicate a slight infestation. A reading between 0.3 and 0.5 per cent indicates either a slight infestation or rather high activity by micro-organisms due to a moisture content higher than 15 per cent. A figure between 0.5 and 1.0 per cent indicates that grain is unfit for prolonged storage.

The authors consider it possible to estimate from the CO_2 figure the number of certain insects which are present within the grains. A one per cent CO_2 figure indicates an infestation of approximately one rice weevil larva per 650 grains or about 25 larvae per pound.

The method has the advantage of being simple to use and does not require the close scrutiny of individual kernels. It has the disadvantage of requiring considerable time to complete a test and does not indicate the presence of dead insects.

Use of Stains

A more rapid method of detecting the presence of weevil infestation within grain was described by Frankenfeld (1948). He employed an acid fuchsin stain whereby the gelatinous weevil-egg plugs were stained a bright cherry red, and feeding punctures and mechanical injury stained a light pink. The stain was prepared by mixing 50.0 ml. glacial acetic acid in 950 ml. of distilled water and adding 0.5 gm. acid fuchsin (Color Index 692). Uniform samples of grain prepared by soaking in warm water for 5 minutes, were immersed in the stain for 2 to 5 minutes after which the excess stain was removed by washing in tap water.

The egg plugs are about the size of an ordinary pin prick and can readily be seen with the naked eye. Goosens (1949) suggested a similar staining method. The wheat is exposed for two minutes in a solution containing ten drops of a one per cent aqueous stock solution of gentian violet in 50 ml. of 95 per cent ethanol. The egg plugs are stained a purple color.

A water-soluble fluorescent dye, berberine sulfate, was suggested by Milner *et al.* (1950) for the same purpose. By this method kernels of wheat are immersed in a dilute solution of berberine sulfate (20 p.p.m.) for one minute, rinsed and examined under ultra-violet light (wave length of 3660A) for the greenish-yellow egg plugs.

Flotation Methods

Studies by White (1956) indicates that a mixture of two solutions of different specific gravity can be used to make a rapid separation of infested from non-infested kernels in a sample of wheat. The mixture consists of a solution of sodium silicate ($Na_2Si_3O_7$) in water with a specific gravity of 1.160 to 1.190 to which is added 1,1,1-trichloroethane adjusted to a specific gravity of 1.30 with deobase oil. When placed together a definite separation level is formed between the two liquids. The lighter sodium silicate solution remains on top of the heavier 1,1,1-trichloroethane-oil solution. Kernels of wheat containing mature or nearly mature larvae float on top of the sodium silicate solution. Kernels containing early stages of weevil larvae and some non-infested light weight kernels are buoyed up to the separation level of the two liquids by the 1.30 specific gravity 1,1,1-trichloroethane-oil solution. Non-infested, normal-weight kernels sink to the bottom.

By placing a 1000-kernel sample of wheat in a glass beaker of the mixture and stirring it to wet the kernels, a quick separation is obtained. If there are no kernels in the top layer the sample can be considered free from serious infestation.

In the presence of floating kernels, the degree of infestation can be estimated by the relationship between the number of floaters and the size of the sample. This test should be of value at the country elevator level where a quick method of detecting infestation in grain is needed.

Apt (1952) proposed the use of a flotation technique whereby a 100-gm. sample of wheat is placed in a two per cent ferric nitrate solution, made by adding two grams of hydrated ferric nitrate to 100 ml. of water. After 30 seconds agitation of the samples to wet the kernels, those with weevil-emergence holes will float and can be counted.

Sodium Hydroxide Gelatinization Method

Apt (1950) proposed a second method for quickly detecting the presence of insect infestation in wheat. This consisted in boiling the kernels for 10 minutes in a 10 per cent solution of sodium hydroxide. The treatment renders the kernels translucent thereby revealing the presence of internal infestation.

Abrasive Method

In 1950, workers at the University of Wichita suggested a novel method of examining samples of wheat for internal insect infestation whereby the samples of grain were glued to a flat surface in a layer, one kernel deep. The kernels were then sanded so as to remove the outer bran coat and expose internal feeding forms. The samples of grain were examined under ultra-violet light so that the fluorescing insect excrement would facilitate the finding of infestation.

Chemical Detection of Insect Phenols

Potter and Shellenberger (1952) described a method of detecting insect contaminates in cereals by a spectrophotometric procedure. The method is based upon the spectrophotometric analysis of dehydroxyphenol which occurs in insect cuticle. These phenols produce phenolindophenol dyes when reacted with 2,6-dichloroquinone chlorimide. According to Milner (1958) the method is promising but will require considerable research to perfect it.

Separation by Air

Milner *et al.* (1953) proposed an ingenious method of using a blast of air to separate infested from non-infested kernels of wheat. They found that a seed blowing device could be adapted to provide a reasonably quantitative segregation of light or weevil cut kernels. The writers claim this device reduces by a factor of ten or better the number of kernels in a given sample which must be examined for infestation.

Detection by Sound

The detection of the presence of insects working inside objects, when they are hidden from view, has been attempted with some success by amplifying the sounds made by the insects in moving or feeding. Recently Adams *et al.* (1953) described a portable apparatus employing a special electronic amplifier and an oscillograph for the aural detection of insects within grain. The difficulty of estimating infestations quantitatively and the impossibility of detecting the presence of dead insects are serious limitations of this method.

Of the several methods proposed for detecting the presence of internal insect infestation within kernels of grain, the two most accurate and most commonly used are the "cracking-flotation" method and the X-ray method. Owing to the high initial cost of X-ray equipment and the added cost of operation, many operators rely on the "cracking-flotation" method.

"Cracking-Flotation" Method

With this method cleaned grain is coarsely ground to release the internal insects and is either soaked in a water-alcohol mixture or in boiling water and then mixed with gasoline or mineral oil. The insects or insect parts are floated off with the oil layer in a Wildman trap flask, collected on a piece of filter paper and counted. In the process of grinding, some of the insects are broken, but characteristic parts such as the heads can be counted and a fairly reliable estimate of the number of whole insects arrived at. A detailed description of the "Cracking-Flotation Method" as used by Harris *et al.* (1952) in their survey of insect contamination in wheat follows:

"Cracking and flotation procedure—After cutting out slightly over 100 gm. with the Jones sampler, weigh out 100 grams. Transfer a small amount at a time onto a 5 or 8 inch No. 12 U. S. standard sieve and brush with a stiff-bristle brush to work the surface insects through the sieve as nearly quantitatively as practicable. Grind the screened wheat in a buhr or Wiley mill set just fine enough to cut the kernels approximately into eighths, or with no granules any coarser than two mm. Transfer all of the cracked wheat to a two-liter trap flask and brush into the container any residue that may remain in the mill after grinding. Add about 400 ml. of 60 per cent alcohol and mix thoroughly. Wash down the sides of the flask with sufficient 60 per cent alcohol to bring the total volume to 700–900 ml. and soak 10 minutes. Add 35 to 50 ml. of gasoline, mix thoroughly, and allow to stand five minutes. Fill with 60 per cent alcohol, allow to stand 30 minutes and trap off into a beaker. Mix 25 to 30 ml. of gasoline into the trap flask, then 5 ml. of 60 per cent alcohol, and after 30 minutes trap off into the same beaker. Filter through a 10XX bolting cloth or if a starchy residue remains add sufficient concentrated HCl to make 1 to 2 per cent acid, bring to a boil, then filter through a 10XX bolting cloth and examine at 15-30X. Count only whole adults, larvae or pupae, or the heads, head capsules, or cast skins from adults, larvae or pupae."

The X-Ray Method

The most accurate and rapid method of determining internal insect infestation in samples of grain was described by Milner *et al.* (1950). By this method, X-ray machines are used to take radiographs of 50 or 100-gm. samples of grain. These radiographs reveal the presence of insect forms within the kernel, so that the skilled laboratory worker can rapidly assess the amount of internal insect infestation. According to Milner (1958):

"This application of radiography utilizes softer radiations than those of normal radiographic technique and thus requires X-ray tubes with beryllium rather than glass windows. Voltages between 15 and 30 kilovolts are most effective. During the perfection of this method it was observed that optimum definition could be achieved only by minimizing the amount of radiation-absorbing materials

between the radiation source and the photographic film. For this reason, the cardboard fronts were cut from conventional X-ray film-holding cassettes, and thin photographic black paper was substituted. Commercial machines which have been developed use cassettes made from plastic materials having low radiation absorption coefficients."

Several commercial concerns are now manufacturing special X-ray instruments for the radiography of grain samples.

According to Milner *et al.* (1953) elimination of the dark room and the wet processing of films is now feasible with special Polaroid radiographic media. Special film packets containing developing and fixing chemicals are used in conjunction with a small self-contained developing device which requires only from 1 to 2 minutes to produce dry finished radiographs. These are adequate for inspection purposes although they do not possess the detail and quality of radiographs made with standard double-emulsion X-ray film.

UNIFORM GRAIN SAMPLES

The reliability of any test for internal insect infestation depends upon the uniformity of the grain sample examined. Unless samples are representative of the bulk grain in carload lots, trucks, or bins of about the same depth as in a carload, samples should be taken by probing with a standard 6-inch long grain trier in five or more places well distributed over the surface of the grain. One or more surface samples can also be taken. In deeper, farm type bins it may be necessary to use an extension probe to sample the lower half of the bin as well.

In elevators, samples can be taken of grain as it is turned, by use of an automatic sampler or by taking samples at frequent intervals from the grain stream with a pelican sampler.

In the case of boats or barges, samples can be taken of the falling grain as they are unloaded, by use of a pelican sampler or similar device.

Grain samples should be thoroughly mixed and cut to appropriate size with the use of a standard grain divider.

EXAMINATION OF MILLED CEREAL PRODUCTS FOR INSECT CONTAMINATION

Milled flours used in the preparation of specialty products, cake or bread mixes, or by millers in preparing blends should always be examined for the presence of both insect infestation and insect contamination. The presence of living infestation in flour can be determined by sifting through a No. 64 wire screen. This will remove most of the eggs, larvae and adults of any insects which may be present.

At least one per cent of the bags of each carload of shipment should be sifted.

Insect Fragments

For the detection of insect fragments in milled cereals, which may be present but are not detectable by microscopic examinations, procedures have been published by the Food and Drug Administration, the Association of Official Agricultural Chemists, and the American Association of Cereal Chemists. Recommendations relative to useful procedures for the examination of food products for extraneous materials that will also be found useful to analysts are contained in the Report of the 1945–46 Committee of the New York Section of the American Association of Cereal Chemists. A bibliography of methods for the examination of food for filth was published in 1957 by the Food and Drug Administration and consists of a joint issue of two bibliographies published by Kenton L. Harris in the Journal of the Association of Official Agricultural Chemists. It is probably the most complete listing of publications in this field now available.

Essentially the process of examining flour for filth consists of digesting the sample with pancreatin or hydrochloric acid, making gasoline or light mineral oil separations of the extraneous material, and identifying the separated material. Harris and Knudsen (1948) in reporting on the efficiency of various filth recovery procedures, describe the two procedures in common use for detecting insect fragments in flour as follows:

"Digestion in pancreatin solution: Weigh 50 gm. of flour into 250 ml. beaker. Add about 60 ml. pancreatin soln. (prepared as a filtered aqueous extract of 5 gm. pancreatin per 100 ml. H_2O) and stir into smooth paste. Add about 40 ml. of the pancreatin soln (100 ml. total) and mix. (Adjust to pH 7–8 with about saturated Na_3PO_4 solution.) Allow to stand about 15 min., and if necessary readjust to pH 7–8. Maintain at 104° F. for not less than 3 hours. Transfer digested material to liter Wildman trap flask. Add 20 ml. of gasoline and mix thoroughly. Allow mixture to stand 5 min., fill with saturated NaCl solution, and after 30 min. trap off into 250 ml. beaker. Add about 10 ml. gasoline to the material in the trap flask, stir the gasoline into the mixture and after about 5 min., trap off into the same beaker. Transfer contents of beaker to trap flask and fill with saturated NaCl solution. Stir and after about 30 min. trap off into beaker and filter through rapid filter paper, using suction. Examine microscopically."

"Digestion in 400 ml. 2 per cent hydrochloric acid: To 50 gm. flour in a beaker add water and stir in a thin smooth paste. Add H_2O to make 400 ml. total H_2O added. Add conc. HCl to make total HCl of water 2 per cent. With intermittent stirring bring to a boil and boil 20 min. Transfer to 2 liter trap flask and trap off with gasoline and water in the usual manner."

In commenting on the above procedures, these authors concluded: that the use of water in the trapping procedure gave significantly higher recoveries than did the use of salt solution; that a second "trapping off" recovers additional filth elements; and that the average insect fragment

count using large quantities of dilute hydrochloric acid was as high as or higher than any of the averages for pancreatin digestion.

Insect Excreta

For the detection of insect excreta in flour the following method given in "Methods of Analysis" of the Association of Official Agricultural Chemists will be found useful:

"Weight 0.20 gm. of flour on tared, flat, glass disk of 7 to 7.5 cm. diam. Add clove oil and spread mixture into thin uniform layer. (There should be sufficient oil present to clear flour and present smooth surface of oil, but not so much that mixture will flow off disk.)

Place wire grid over disk and examine microscopically with dark background and intense reflected light."

Identification of Insect Fragments[1]

In the extraction of insect fragments from food products it has been found that the mandibles of the insects are relatively resistant to grinding, are readily recovered in substantial numbers and are easily examined microscopically. Kurtz *et al.* (1952) studied the mandibles of a number of the common stored grain insects and published a key for their identification. Illustrations were also provided. Heuermann and Kurtz (1955) have published a paper dealing with the elytral patterns of some 20 insects associated with food products, whereby small pieces of the elytra could be used to identify insect species. Such information is of value in that it may indicate the origin of an infestation of milled cereal products, by accurately identifying the insect or insects involved.

INSECTICIDAL RESIDUES

In the control of insect infestations in grain and milled products chemical fumigants are used which leave residues. The provisions of the Miller Amendment to the Food, Drug and Cosmetic Act stipulate that the residue of any pesticide remaining in or on raw agricultural products as a result of using such pesticide in the production or preservation of the product, must not exceed tolerances established under the Act. All grains are classed as raw agricultural products. Milled products such as flour, corn meal, brewers grits, oatmeal, cottonseed meal and mixed animal feeds are not classed as raw products, but fall under the provisions of another section of the Act; and tolerances for residues must be established separately for these products.

[1] Announcement has been made (1958), that the Bureau of Biological and Physical Sciences, Food and Drug Administration, Washington, D. C., has begun preparation of an authoritative and comprehensive volume on insects and insect fragments which cause adulteration of foods and drugs.

Many of the common grain fumigants such as carbon disulfide, carbon tetrachloride, ethylene dichloride and chloropicrin are exempt from the need for a tolerance, since their residues disappear rapidly or do not remain in amounts sufficient to be hazardous. Tolerances of 25 parts per million of hydrocyanic acid and 50 parts per million of inorganic bromide have been established for grain. Residues of hydrocyanic acid in grains resulting from fumigation with either calcium cyanide or liquid hydrocyanic acid, are transitory so that repeated fumigations do not normally create a problem.

Residues of inorganic bromide will result from fumigation with methyl bromide or liquid fumigants containing ethylene dibromide. This residue is said to be the result of a methylation process in the protein of the grain, resulting in the formation of an inorganic bromide. This residue is fixed and cannot be removed. Each time grain is fumigated with these products, additional residues of inorganic bromide accumulate. Such residues also accumulate in milled cereal products as a result of fumigation with methyl bromide.

Excessive residues of inorganic bromide as a result of repeated fumigations may cause disagreeable odors in bakery products or the 50 p.p.m. tolerance may be exceeded.

Where the history of previous treatments of raw grain or milled cereal products is unknown, the user would do well to have the inorganic bromide content determined before purchase. Such analysis can be performed by commercial laboratories or by the manufacturer of methyl bromide.

THE RODENT PROBLEM

Rodents destroy grain and grain products, contaminate it with their filth, and carry at least 10 diseases, including Bubonic plague, murine typhus, spirochetal jaundice, tularemia, Leptospirosis (Weil's disease), trichinosis, rabies, rat-bite fever, rickettsial pox, and bacterial food poisoning.

According to an estimate by the Fish and Wildlife Service, (Mills 1953) there are at least 100 million rats in the United States each of which costs us an average of $10 a year or a total of over one billion dollars. Mice are a great deal more numerous and universally distributed than rats. According to Dykstra (1954) over 300 different native forms inhabit portions of North America with a total population of over a billion. So-called plagues of mice sometimes occur, and their numbers may reach astronomical proportions. Such an outbreak took place in California during 1926 when infestations were estimated to total 80,000 per acre.

Both rats and mice possess a high reproductive capacity. Dykstra states that while their breeding rate is usually greatest during spring and fall, 20 to 30 per cent of the female rats are always pregnant. About 3,500,000 rats are born daily in the United States. Many of them die through natural mortality, but in one year's time a pair often produce 60 to 70 offspring that survive to maturity.

The female meadow mouse is said to be "unpregnant" only 10 per cent of her life and the household variety is not far behind. One pair may have 40 to 60 surviving offspring each year.

The Norway Rat

The brown or Norway rat (*Rattus norvegicus* Erxleben) is the most abundant and troublesome of the rats that attack grain in storage. Originating in Asia, it has spread to many parts of the world including the United States and Canada.

This large, brown rat lives in burrows around grain bins and under buildings or may nest in sheltered locations on the first floor of buildings. It is about 16 inches long and when full grown averages about $^3/_4$ pound in weight. Rats stay within 75 to 100 feet of their burrows unless forced to travel further for food. They may feed at any time of the day or night;

Courtesy of U. S. Fish and Wildlife Service

FIG. 164. RATS NOT ONLY DESTROY GRAIN BUT RENDER TEN TIMES THE AMOUNT THEY EAT UNFIT FOR HUMAN CONSUMPTION

but they are most active after dusk. Food in exposed locations almost always is removed to a protected site before it is eaten. The Norway rat begins to breed at 3 or 4 months of age. The gestation period is from 21 to 25 days so it would be possible for a female to have as many as 12 litters a year. Actually they average from 3 to 5 liters a year; litters vary in size from 6 to 22 young but average from 8 to 10.

According to Mills (1953) each rat is capable of consuming 40 lbs. of grain per year. They may render 10 times that amount unfit for human consumption. In all, they are reported to destroy 200 million bushels of grain a year (Fig. 164).

The House Mouse

The imported house mouse (*Mus musculus* Linnaeus) is the most destructive of our mouse pests, and is said to be an even greater despoiler of grain than the rat.

The house mouse is one of the smallest of the rodents. It is brown in color, with pale underparts and weighs between $^1/_2$ ounce and $^3/_4$ ounce when mature. The females may have 6 or 7 litters of 5 or 6 young each year. In spite of their small size, a pair may consume four pounds of food during the fall and winter months. As a rule the house mouse does not travel far but prefers to remain within a few feet of its nest and food supply. They rarely travel outside an area of 50 square feet. In nature they may live about a year unless they meet with accidents.

RODENT CONTAMINATION

Rodent contamination of grain starts in the field. Many species of mice live in the open fields the year around and grain fields supply abundant food and shelter for them. When the heads of small grains become heavy and bend over, the mice feed upon them and deposit their filth so that some of it is picked up in the process of harvesting. The temporary piling of grain in the open at harvest time adds to the danger of contamination. In the case of combined grain, the combine harvester itself may be a source of contamination. It may become contaminated with rodent droppings while it is stored over winter in farm machinery sheds without cleaning, or when left in the field overnight during the harvest season. Samples of grain taken directly from the combines indicate that from 5 to 9 per cent of the combined wheat in some areas already contains evidence of rodent filth in the form of droppings.

During storage on the farm, and as it passes through the various phases of storage from the field to the processing plant, rodents may have free access to grains. They contribute their droppings, urine, fur and carcasses in large quantities. According to Dykstra (1954) a single

pair of rats living in a granary or warehouse during six fall and winter months eliminate around 70 droppings per day. Their six months' accumulation is about 25,000 droppings with a total weight of between 2 and 4 lbs.

One rat voids about 16 ml. of urine in 24 hours. The total volume from a pair in six months equals about 1 1/2 gallons. They constantly shed particles from their dirty coats of some 500,000 hairs. The amount of other forms of filth carried by them cannot be estimated.

Similarly, a single pair of house mice living in a granary eliminate about 48 droppings per day and void 0.5 ml. of urine in 24 hours.

All of this filth does not fall into food material but enough of it does to create a serious problem. When it is considered that one rodent pellet per pint of wheat renders this wheat subject to seizure, the daily droppings from one rat could render one bushel of grain unfit for milling.

During 1952 some sixty cars of wheat contaminated with rodent filth were diverted through Federal action from food to feed channels.

One Midwest firm reported 100 or more rodent pellets per bushel of corn in 58 per cent of 1,393 cars unloaded for milling purposes.

A survey of corn conducted by the Food and Drug Administration gave evidence of rodent filth in 90 per cent of over 1000 samples taken at terminal markets. One-sixth of the cornmeal entering retail channels in a Southern State was declared by the State Chemist to be unfit for human food. In another area 47 per cent of 34 samples from canned corn on grocery shelves contained rodent hairs.

In the course of an investigation by Food and Drug Administration officials on rodent contamination of wheat and wheat flour and of corn and corn meal (Harris *et al.* 1952 and 1953), interesting figures were obtained regarding rodent contamination in market grain reaching commercial mills and the efficiency of cleaning machinery in removing their filth.

Rodent Contamination of Milling Wheats

Based on a survey of 1,411 wheat samples collected from 109 mills used as sampling points 23.1 per cent were contaminated with rodent pellets on a 1000-gm. pickout test. There was a tendency toward higher contamination in wheat from the Dakotas, Nebraska, Minnesota, Iowa, Illinois, Indiana and Ohio. There was a decrease in infestation from May to September with the marketing of new crop wheat, and a rise in October which continued through the winter months. The relationship between rodent contamination and type of storage from which wheat samples originated is shown by the data of Table 144.

The type of wheat had no significant influence on rodent contamination.

Mill cleaning reduced the average number of rodent pellets in wheat at practically all mills in which studies were made with an over-all reduction from 0.35 to 0.13 per 1000 gm.

As shown by the data of Table 145, there is a positive relationship

Table 144

RELATION OF RODENT PELLET CONTAMINATION TO TYPE OF STORAGE—PICKOUT FROM 1000 GM.[1]

Type of Storage	Number of Samples	Number of Rodent Pellets Range	Average
Direct from harvest	25	0– 5	0.20
Farm	42	0– 7	0.62
Country elevator	782	0–19	0.56
Terminal elevator	542	0– 7	0.32
Other and unknown	19[2]	0– 4	2.00
Total or averages (over-all)	1410	0–19	0.48

[1] Harris *et al.* (1952).
[2] One sample counting 30 pellets omitted.

Table 145

COMPARISON OF RODENT HAIRS IN FLOUR TO RODENT PELLETS IN THE UNCLEANED AND CLEANED WHEAT[1]

Rodent Hairs per 50 Gm. Flour	No.[2]	Per cent	Rodent Pellets in Uncleaned Wheat[3] Range	Average	Rodent Pellets in Cleaned Wheat[3] Range	Average
0	132	62.7	0–3	0.20	0–1	0.06
1	63	29.5	0–3	0.52	0–2	0.29
2	13	6.3	0–4	0.62	0–1	0.08
3	2	1.0	1–1	1.00	0–1	0.50
13	1	0.5	..	6.00	..	1.00
Total and averages (over-all)	211	..	0–6	0.35	0–2	0.14

[1] Harris *et al.* (1952).
[2] Figures in this table limited to 211 samples on which all analyses were completed. Some cleaned wheats were so cracked that examination was impracticable.
[3] Visual examination of 1000 gm.

between the number of rodent pellets in wheat and rodent hairs in the flour made from it.

Rodent Contamination in Milling Corn

The United States Food and Drug Administration survey showed that substantial proportions of both white and yellow corn purchased by millers are contaminated with rodent pellets. Only ten per cent of the samples taken showed no pellets per peck of corn.

Mill cleaning does remove substantial proportions of both rat and mouse pellets but in some cases, pellets were found in the cleaned corn going to the rolls.

There was a relationship between the number of rodent pellet frag-

ments and/or rodent hair fragments in bolted corn meal and the rodent pellet findings in the cleaned corn from which the corn meal was made.

DETECTION OF RODENT CONTAMINATION

Visual Examination

The rodent pellet pickout method of determining rodent contamination of grain is a practical test that requires no special training or equipment.

In the case of wheat the sample can be examined by spreading a small portion at a time on a piece of white paper or a white painted surface.

Corn can be examined in the same manner; however, since mouse pellets can be removed from corn by sieving, the sample should be run over a No. 6 sieve. The rat pellets then can be picked out in the manner described for wheat.

Analytical

Analytical procedures for determining rodent pellet fragments and rodent hairs in whole, bolted or degerminated corn meal or corn grits have been described by Harris *et al.* (1953) as follows:

1. "**Rodent Pellet Fragments:** Weigh a 50 gm. portion of the well-mixed sample into a 250 ml. hooked lip beaker. Add chloroform to within one-half inch of top, mix thoroughly, and allow to settle at least 30 minutes. Several times during this period, stir layer that rises to top. Decant chloroform and floating corn tissue onto a filter paper in a Buchner funnel, taking care not to disturb the heavy residue in bottom of beaker. Before decanting, take care that floating layer has not become so compact as to render this operation difficult. Add a quantity of carbon tetrachloride equal to the quantity of chloroform and corn tissue left in beaker, allow to settle again, and decant as before. With a mixture of equal parts of chloroform and carbon tetrachloride, repeat this process until very little corn tissue remains in the beaker. The material in the Buchner funnel is used for Part 2 below. Be careful not to decant any rodent pellet fragments that may be present. Wash the residue in the beaker onto a seven-cm. ruled filter paper, using a stream of chloroform or carbon tetrachloride, and examine microscopically at 30×. Count the rodent excreta fragments identified by the presence of rodent hairs. Do not count particles resembling excreta fragments unless hair is attached.

2. "**Rodent Hairs:** Draw air through the material in the Buchner funnel until the liquid has evaporated. Air dry until no odor of chloroform remains and transfer the residue to a one liter Wildman trap flask. Add 100 ml. of 60 per cent alcohol and mix thoroughly. Wash down the sides of the flask with the alcohol until about 300 ml. is added, and soak thirty minutes. Add about 35 to 50 ml. of gasoline, mix thoroughly, and allow to stand five minutes. Fill with the alcohol, allow to stand 30 minutes and trap off into a beaker. Rinse the neck of the flask with alcohol, then with water, collecting the rinsings in same beaker. Add about 10 ml. gasoline to the trap flask, mix down into the liquid, add sufficient 60 per cent alcohol to bring the floating gasoline layer

up into the neck of the flask and, after about 30 minutes, again trap off into the same beaker. Rinse neck of the flask as before. Filter, and examine microscopically at 30×. Count the rodent hairs.

"In the case of cream meals, corn flour and similar products consisting largely of finely ground material, use the same procedure as for whole corn meal for detecting rodent pellet fragments. For detecting rodent hairs, proceed as for whole corn meal except substitute saturated NaCl solution for 60 per cent alcohol."

For determining rodent hairs in flour follow the technique suggested for the examination of filth in flour described in the section on insect contamination.

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